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THE EFFECT OF LIGNOSOL ON THE
PHYSICAL PROPERTIES OF SOILS .
INCLUDING ITS EFFECT ON THEIR
SUSCEPTIBILITY TO FROST ACTION

THESIS
1947
#14

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FACULTY OF APPLIED SCIENCE

This is to certify that the undersigned have read and recommended to the Committee on Graduate Studies for acceptance, a thesis submitted by R. A. Hemstock, B.Sc. "1943", and S. R. Sinclair, B.Sc. "1944", entitled:

The Effect of Lignosol on the Physical Properties of Soils Including Its Effect on Their Susceptibility to Frost Action.

THESIS

THE EFFECT OF LIGNOSOL ON THE PHYSICAL PROPERTIES OF SOILS INCLUDING ITS EFFECT ON THEIR SUSCEPTIBILITY TO FROST ACTION

Submitted as the Partial Fulfillment
of the
Requirements for the Degree of
Master of Science

by

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and
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Under the direction of
R. M. Hardy

University of Alberta April 11th, 1947.
Edmonton, Alberta.

Thesis
1947
#14

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ABSTRACT

This investigation was conducted to determine the effects of lignosol(1) on the engineering properties of a test soil, with special reference to frost heaving. The program included laboratory tests to determine:

1. The effect of the admixture on the frost heaving properties of the soil.
2. Whether its use as a frost deterring agent impairs the other properties which determine the soils usefulness in highway and airport construction.

It is concluded, as a result of this investigation that the lignosol has a marked effect in reducing frost heave in this soil without impairing its other engineering properties.

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(1) A waste product of the pulp and paper industry, containing sugars and other organic matter. See page 9.

II

INTRODUCTION

Frost heaving has always been a serious problem for highway and airport engineers, but, the present extensive development of the North has magnified this problem greatly. This development has made it more important than ever that there be a thorough understanding of frost action, and, that new and better methods for prevention of frost damage be developed.

In the past, some of the damage has been prevented by one or more of the following general methods:-

(a) Replacement of detrimental subgrade with good material.
(b) Drainage of subgrade and underlying soil.
(c) Treatment of existing subgrade soil.
(d) Stabilized soil base construction.

These methods have generally proven unsatisfactory, either because of almost prohibitive expense, construction difficulties, or the transitory nature of the treatment.

The purpose of this investigation was to determine the effects of lignosol when used as an admixture in soil, with special reference to:-

(a) Its effectiveness in reducing frost heaving.
(b) The relation of amount of admixture to percentage heave.
(c) Its effect on the other engineering properties of the soil.

A complete description of apparatus, test procedure, results and conclusions is presented.

III

HISTORY OF FROST ACTION INVESTIGATIONS

Scientific study of the true physical processes of frost action in soils began about thirty years ago. Previously, it was believed that frost heaving was simply due to the freezing of the water initially present in the soil.

Dr. Stephen Taber(15), one of the chief investigators in this field, carried out extensive research which proved that the above explanation was not sufficient. Frost heaves up to sixty-five percent of the original volume of soil had been recorded, which showed that some other explanation of this phenomenon was necessary. Taber summarizes his hypothesis(17) as follows:

"Frost heaving is due to the growth of ice crystals and not to change in volume. Pressure is developed in the direction of crystal growth which is usually determined chiefly by the direction of cooling. Excessive heaving results when water is pulled up through the soil to build up layers or lenticular masses of segregated ice, which grow in thickness because water molecules are pulled into the thin film that separates the growing columnar ice crystals from the underlying soil particles."

Mullis(12) and Benkelman and Olmstead(2) have suggested an alternate theory by which they attempt to ex-

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(15) Numbers refer to bibliography.

plain the formation and growth of ice lenses. This theory, although possibly applicable in a few cases, is not generally accepted.

A. Casagrande has stated(5) that:

"Under natural freezing conditions and with sufficient water supply, one should expect considerable ice segregation in non-uniform soils containing more than three percent of grains smaller than 0.02 mm., and in very uniform soils containing more than ten percent smaller than 0.02 mm. No ice segregation has been observed in soils containing less than one percent of grains smaller than 0.02 mm., even if the ground water level was as high as the frost line."

This eliminates the possibility of heaving in clean sands and gravels, because capillary movement of water through these soils is impossible. Clays, although capable of capillary action, are not permeable enough to allow sufficient passage of water for the formation of ice lenses. Thus, it is found that most damaging frost heave occurs in silty soils. Taber, Beskow(3) and others have verified this. statement.

Winn and Rutledge(18) summarize the generally accepted conclusions of former investigators as follows:

1. Destructive frost heaving is almost invariably associated with the formation of segregated ice.

2. The total amount of frost heaving is very closely

equal to the sum of the thicknesses of all layers of segregated ice in the frozen soil.

3. The total amount of frost heaving is in direct proportion to the increase in total water content of the frozen soil.

4. The soil must have a water content at least equal to a state of capillary saturation for ice segregation to take place.

5. A supply of water must be available for the growth of ice crystals, either from some portion of the soil itself or from some external source, e.g., ground water table.

6. For normal field conditions of temperature, a certain minimum percentage of grains smaller than 0.02 mm. is necessary for ice segregation in soil.

7. One slow, gradual decrease in temperature well into the freezing range is necessary and sufficient to cause ice segregation and frost heaving. Subsequent thawing and refreezing may increase the severity of the frost heaving but will not change the basic action.

8. A cumulative curve of degree-hours of freezing plotted against time is a qualitative measure of the increase of frost heaving with time.

9. The following factors are all necessary for ice segregation and frost heaving. If any one of these factors is not present, frost heaving will not occur:

(a) Capillary saturation of the soil at the beginning of, or during, the freezing process.

(b) A free supply of water from within or without the soil.

(c) A minimum percentage (3 to 10 per cent) of grains smaller than 0.02 mm.

(d) A gradual decrease in temperature of the air above the soil to below freezing temperatures.

Hogentogler (8) states that "the water furnishing ability of a soil is the most important single factor in the formation of ice lenses."

It is necessary, then, if frost heaving is to be prevented, to alter or eliminate one or more of the factors listed under 9, above. From a practical standpoint, preventative measures which have been developed to date, principally by highway engineers, include:-

1. Elimination of water supply. This may be accomplished by:-

(a) Lowering ground water elevation by ditches or drains. This method is not applicable to fine grained soils.

(b) Isolating soil susceptible to frost action by a blanket of material placed near the frost line, to interrupt capillary travel of water. Such blankets may include sand, gravel, cinders, or water-tight bituminous

layers. It is impossible, of course, to isolate soil by this method if the ground water level lies above the frost line.

(c) Prevention of capillary travel of water by admixtures.

2. Complete removal of soil susceptible to frost action and replacement by a non-susceptible material. This is generally an expensive procedure.

3. Prevention of freezing in the soil by:-

(a) Application of an insulating layer to prevent the formation of a frost line where it would induce heaving.

(b) Lowering the freezing point by the use of admixtures.

The Engineering Experiment Station of Purdue University began in 1938, an extensive investigation of frost action in soils treated with admixtures(18). The admixtures investigated include sodium chloride, calcium chloride, calcium oxide, portland cement, tar, emulsified asphalt, cut-back asphalt, road oil and vinsol, a by-product of turpentine distillation. None of these admixtures were found to be completely satisfactory in deterring damaging frost action although under certain special conditions, some were effective.

IV

PROCEDURE

MATERIALS

For the purposes of this test, a soil was required that was fairly permeable and had the desired grain size so that frost lenses could easily be formed.

A suitable soil was found at the Barrier Site of the Calgary Power Company. This site is located on the N.E. 1/4 of Sec. 9, Tp. 24, R. 8, W. 5, approximately seven miles up the Kananaskis River from Seebe. The soil is a fine grained uniform grey silt--a glacial lake deposit. Examination under a petrographic microscope showed that it consisted mainly of small uniform quartz grains with limey interstitial material. A few heavy minerals, probably magnetite and zircon were present.

A soil sample of about four hundred pounds was obtained. It was uniform throughout and after a thorough mixing and drying, it was stored until required.

The lignosol used is a waste product of the pulp and paper industry. It is often referred to as sulphite liquor. It had been refined to reduce the moisture content--an analysis showed it to contain approximately 50 per cent water, 15 per cent sugars, 30 per cent other organic material and traces of lime and calcium monosulphite. In appearance it resembles molasses. It is a dark viscous

liquid, smooth and sticky in texture. It is completely soluble in water, and is therefore easily applied in any strength as a solution to the soil particles.

REFRIGERATION APPARATUS AND ARRANGEMENT

The refrigerating equipment used for this work consists of one built-in refrigeration room of range -30° to +10° C. In this room there was available a well insulated cabinet. By utilizing this cabinet the experiment was set up in such a way that the top of the soil specimens could be subjected to an air temperature below freezing and the bottom of the sample would be in contact with a supply of water at all times. This is illustrated in Figure 1.

The water in the cabinet was kept from freezing by a rheostatically controlled heating coil. The soil samples were made up in lucite cylinders 2¼ inches in diameter by 6 inches long. These were placed in two rows of three in the box and the surrounding space filled with a mineral insulating material.

FROST SAMPLES AND TESTS

It has been found by other investigators that the following factors affect the amount of heaving in soils susceptible to the formation of ice lenses.

1. Temperatures at the top and bottom of the soil sample.
2. Duration of constant temperature conditions.
3. Initial density.

4. Initial degree of saturation.

There were two sets of freezing tests run. Each set was comprised of six samples of soil, varying in the amount of admixture from 0 to ten per cent(1). Thus the temperature conditions and duration of test were eliminated as variables for all the samples in the same set. They varied, however, from one set to another, because of the lack of adequate temperature control.

The next step was to eliminate variation in initial density of the samples, and, if possible, variation in initial degree of saturation.

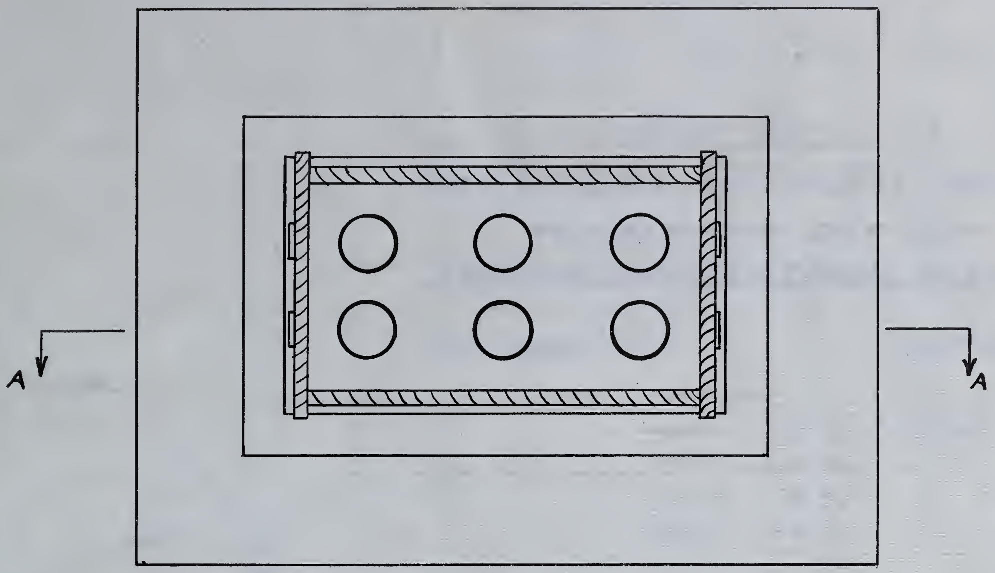
A convenient size of sample was found to be six inches in height and two and one-quarter inches in diameter. Because of the distinct advantages of having the soil samples encased in an open tube while the freezing tests were being conducted, it was desirable to compact the soil directly in the lucite cylinders as shown in Figure 1. The following procedure was then observed:

1. A standard Proctor density test was run on the silt and the results plotted as shown in Figure 2. The standard optimum was determined to be 110 lbs. per cu. ft. at a moisture content of 14.5 per cent.(2)

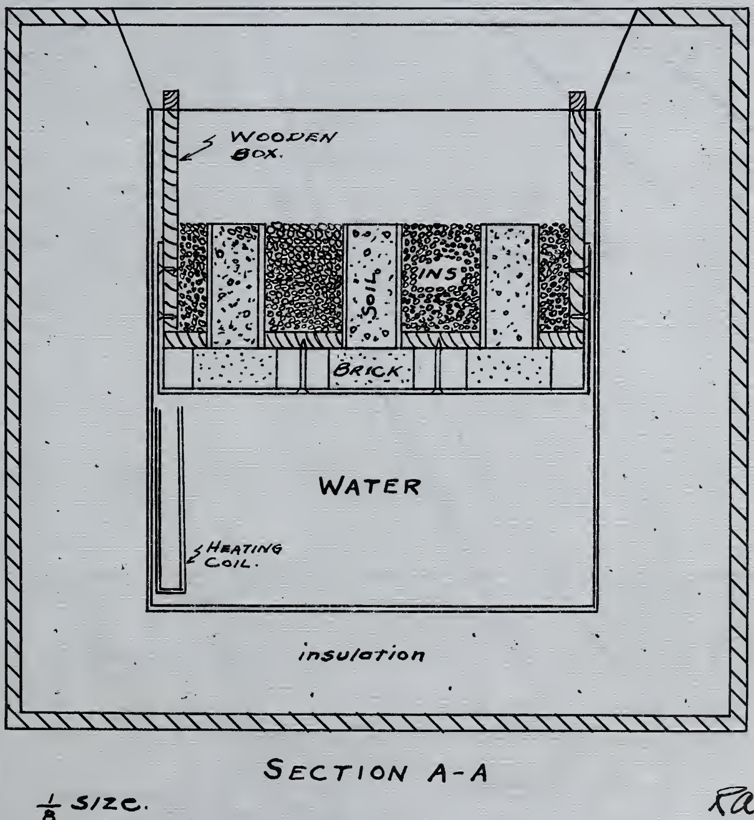
---

(1) $$\text{Admixture \%} = \frac{\text{Wt. of Sulphite Liquor}}{\text{Wt. of Dry Soil}}$$

(2) $$\text{Moisture Content \%} = \frac{\text{Wt. of Water}}{\text{Wt. of Dry Soil}}$$



PLAN

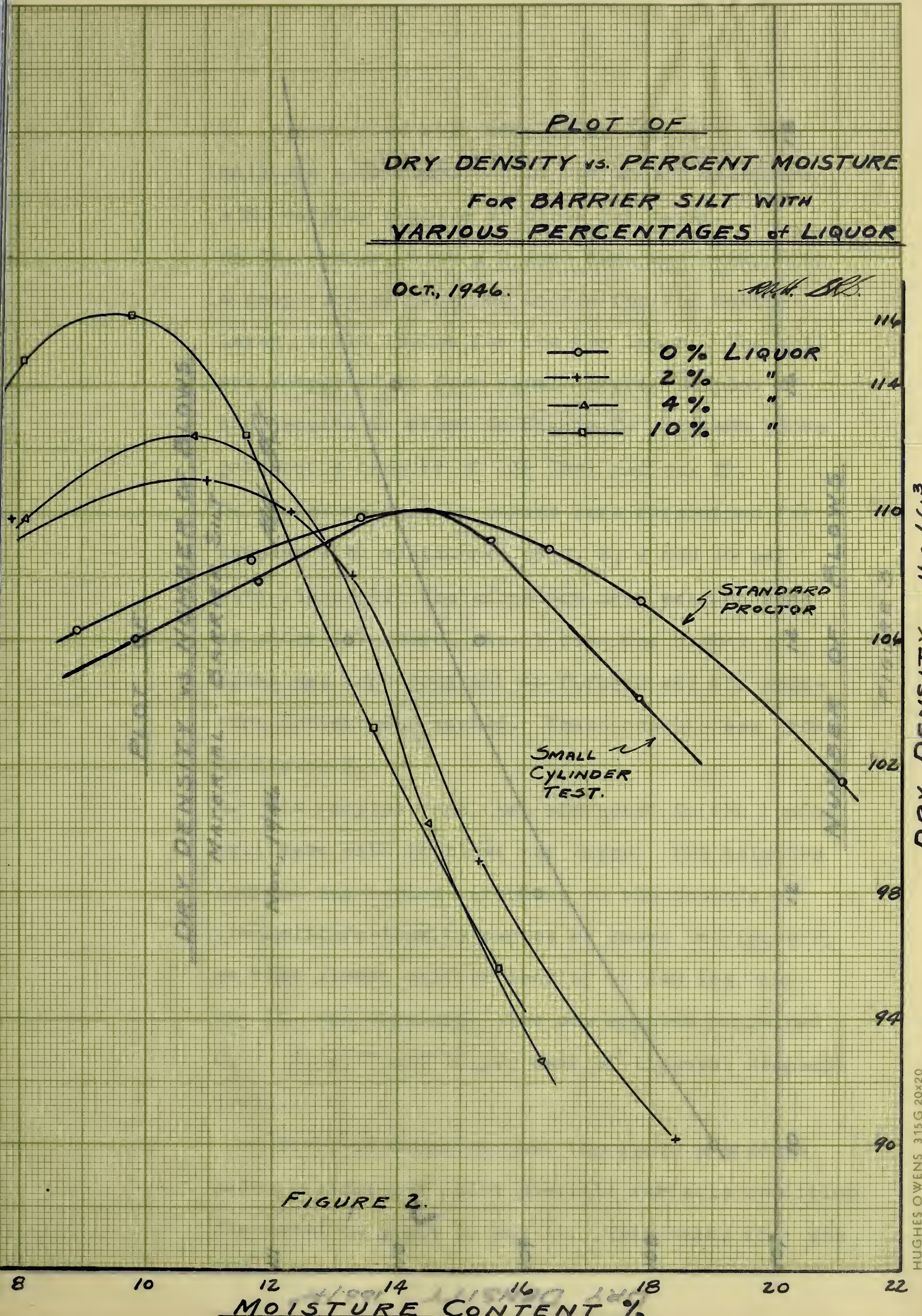


SECTION A-A

$\frac{1}{8}$ size.

R.a.H. S.R.S.

FIG. No. 1.
SKETCH OF FREEZING CABINET



PLOT OF

DRY DENSITY vs. PERCENT MOISTURE

FOR BARRIER SILT WITH

VARIOUS PERCENTAGES of LIQUOR

OCT., 1946.

FIGURE 2.

HUGHES OWENS 315G 20X20

PLOT OF

DRY DENSITY VS. NUMBER OF BLOWS

MATERIAL - BARRIER SILT

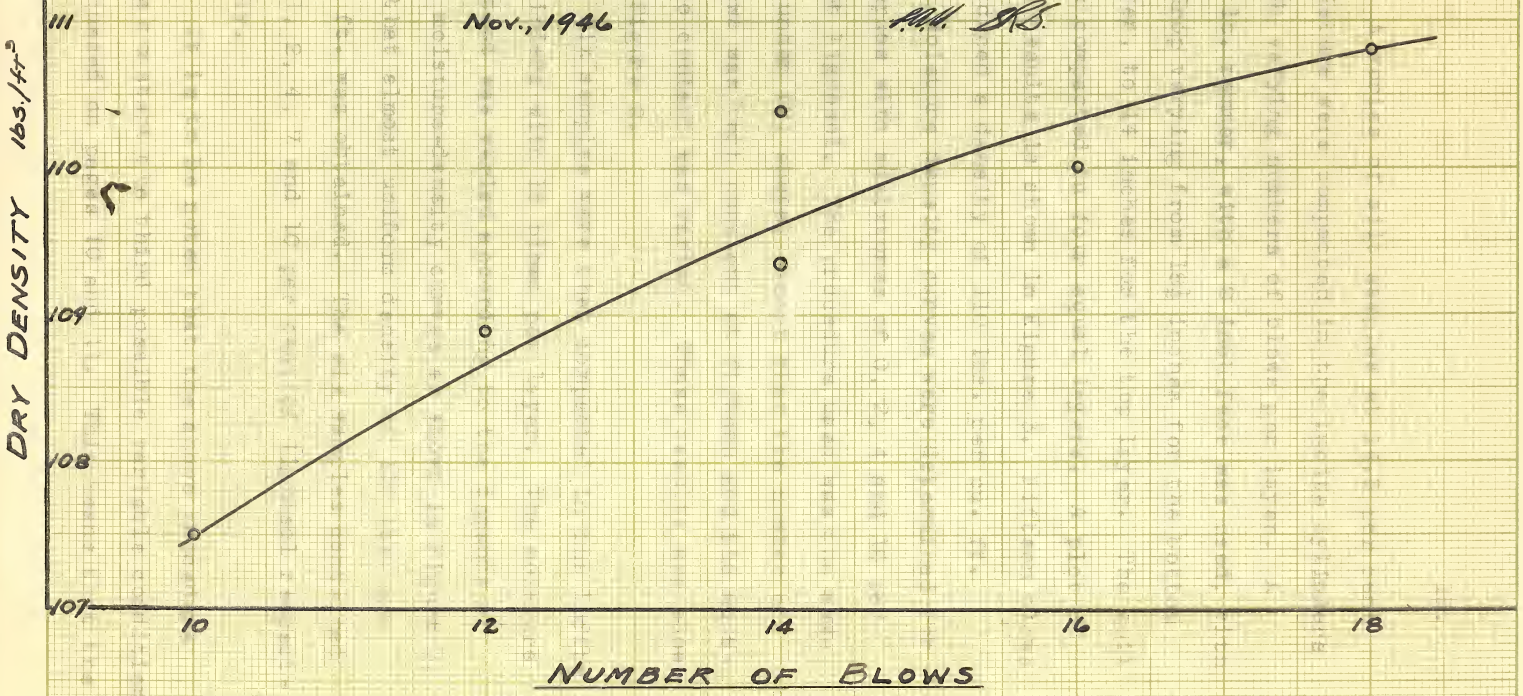


FIGURE 3

HUGHES OWENS 315G 20x20

2. A series of silt samples at 14.5 per cent moisture were compacted in the lucite cylinders with varying numbers of blows per layer. A $5\frac{1}{2}$ lb. rammer, with a 2 inch face was used, with a drop varying from $18\frac{1}{2}$ inches for the bottom layer, to 14 inches for the top layer. The soil was compacted in four equal layers. A plot of the results is shown in Figure 3. Fifteen blows produced a density of 110 lbs. per cu. ft.

3. Moisture density curves were determined for samples with admixtures of 0, 2, 4 and 10 per cent lignosol. The procedure used was the same as under (2) above, except that the number of blows was kept constant at fifteen and the moisture content was varied. These results are shown in Figure 2.

4. Six samples were then compacted in the lucite cylinders with 15 blows per layer. The moisture content was varied according to the demands of the moisture-density curves as shown in Figure 2, so that almost uniform density of 110 lbs. per cu. ft. was obtained. The six samples contained 0, 1, 2, 4, 7 and 10 per cent of lignosol respectively.

It is to be noted that the above procedure made constant the third possible variable condition discussed on pages 10 and 11. This means that the

only variable among the samples of one set, aside from the amount of admixture, was the initial degree of saturation. It was assumed that this would be quickly remedied by capillary action, as soon as the samples were subjected to water at their bottom surfaces.

5. The samples were then placed in the prepared box, insulation was placed around them flush with their surface, and the whole box was placed in the insulated cabinet in the frost room, as shown in Figure 1, and Figure 4.

6. Freezing temperatures at the top of the samples and a source of water at the bottom were maintained as described previously. The test lasted 25 days, the freezing temperature being lowered about once a week, depending upon the amount of heaving that had taken place.

7. Heave was measured with a steel rule, graduated in hundredths of an inch. Mercury thermometers in the frost room and water were used to measure temperature.

8. All data was recorded as shown on enclosed data sheets.

9. A second set of tests was run as outlined under 4 to 8.

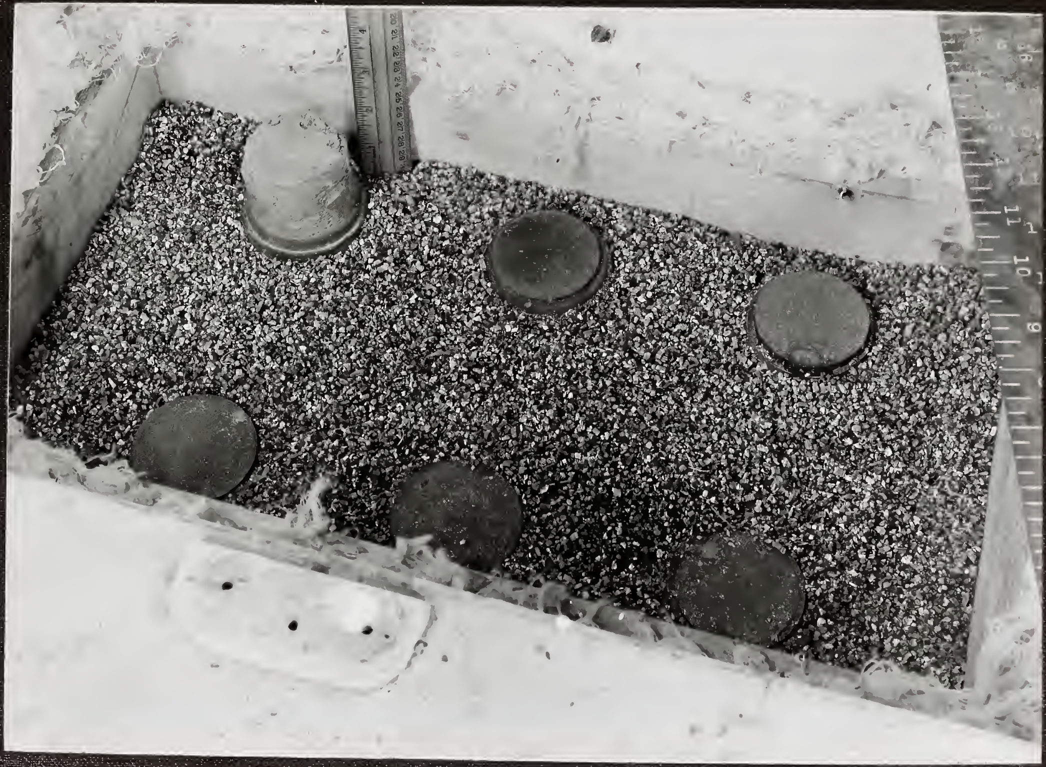


FIGURE 4

OTHER TESTS

The following tests were performed on the material noted according to the methods outlined by 'Notes on Soil Testing for Engineering Purposes', by A. Casagrande and R. E. Fadum, 1940, with the noted exceptions.

1. Grain Size Distribution (Hydrometer Method) - silt. Time of mixing - 5 minutes. Dispersing agent - calgon.
2. Specific Gravity Determination - silt.
3. Atterberg Limit Tests.
    a. - silt.
    b. - silt plus 10% lignosol.
4. Consolidation Tests - including permeability analyses.
    a. - silt.
    b. - silt plus 10% lignosol.
5. Triaxial Compression Tests.
    a. - silt.
    b. - silt plus 4% lignosol.

V

DATA

The data is presented in the following order:-

(A) Grain size determination.

(B) Specific Gravity determination.

(C) Density tests.

(D) Freezing tests.

(E) Atterberg limits tests.

(F) Consolidation tests.

(G) Shear tests (Triaxial).

HYDROMETER ANALYSIS

Sample - Barrier Silt

Method - Harvard

(Mixed 5 min; with 100 drops of Calgon)

Moisture Content

Tare	20.0605 gms.
Tare + Wet Soil	38.1365 gms.
Tare + Dry Soil	38.1047 gms.
Moisture	.0318 gms.

% Moisture = $\frac{0.318 \times 100}{18.0442}$ = 0.18 %

Sample

Tare	131.18 gms.
Tare + Wet Soil	196.18 gms.
Wet Soil	65.00 gms.

Dry Soil = $\frac{99.82 \times 65.00}{100}$ = 64.8 gms.

Date	Temp.	Time	Elapsed Time	R'_H	$R_H = R'_H + C_m$	D in MM.	$R_H + m_t - C_d$	W%
Dec. 6	24.8°	9.03½	½'	33.0	33.3	0.055	33.9	82.7
6	24.8	9.04	1	28.0	28.3	0.043	28.9	69.0
6	24.8	9.05	2	23.8	24.1	0.033	24.7	60.3
6	24.8	9.08	5	15.4	15.7	0.023	16.3	39.8
6	24.8	9.18	15	9.0	9.3	0.014	9.6	23.2
6	24.8	9.33	30	7.0	7.3	0.0105	7.9	19.4
6	24.9	10.03 a.m	60	6.0	6.3	0.0074	6.9	16.8
6	25.2	11.03	120	5.1	5.4	0.0053	6.0	14.6
6	25.9	1.51 p.m	288	4.2	4.5	0.0034	5.3	12.9
6	27.2	5.05	482	3.3	3.6	0.0026	4.7	11.5
7	25.2	8.45 a.m	24 h	3.0	3.3	0.00155	3.6	8.8
9	25.2	9.45	73 h	2.9	3.2	0.00090	3.5	8.5
Large Bulb Hydrometer								
7	27.2	8.45	24 h	3.0	3.3	0.0011	4.2	10.2
9	25.2	9.45	73 h	2.9	3.2	0.00063	3.5	8.5

SPECIFIC GRAVITY TESTS

Nov. 8, 1946

Sample - Barrier Silt

Procedure - as in Harvard Manual.

Tare	84.15 gms.
Tare + Soil	164.43 gms.
Soil	80.28 gms.
W_{bs}	705.35 gms.
From Calibration Curve W_{bw}	654.30 gms.
Temperature	23.6° C.

Therefore -

$$\text{Specific Gravity} \quad \frac{80.28}{80.28 + 654.30 - 705.35}$$

$$= \underline{2.74}$$

Check Test

Tare + Soil	169.96 gms.
Tare	84.16 gms.
Soil	85.80 gms.
W_{bs}	708.77 gms.
From Calibration Curve W_{bw}	654.28 gms.
Temperature	23.9 °c

$$\text{Specific Gravity} \quad \frac{85.80}{85.80 + 654.28 - 708.77}$$

$$= \underline{2.74}$$

MOISTURE - DENSITY TEST #1

Material - Barrier Silt   Date Tested - October 10th, 1946   Volume of Mold - $\frac{1}{29.4}$ cu.ft.

MOISTURE CONTENT	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6
Water Added (Approx.%)	12	18	21	9	13.5	16.5
Wt.Cont.Plus Wet Samp. g.	226.42	253.80	233.30	220.77	246.70	265.71
Wt. Cont.Plus Dry Samp. g.	212.56	230.23	208.31	210.70	228.02	242.58
Wt. Cont. g.	94.52	97.13	89.28	97.13	89.28	101.58
Wt. Water g.	13.86	23.57	24.99	10.07	18.68	23.13
Wt. Dry Soil g.	118.04	133.10	119.03	113.57	138.74	141.00
% Moisture	11.74	17.71	20.99	8.87	13.46	16.40
DENSITY						
Wt.Mold Plus Wet Soil g.	7907	7981	7928	7305	7442	7473
Wt. Mold g.	6035	6035	6035	5520	5520	5520
Wt. Wet Soil g.	1872	1946	1893	1785	1922	1953
Wt. Dry Soil g.	1675	1653	1565	1640	1694	1678
Dry Bulk Density lbs. cu.ft.	108.6	107.2	101.5	106.3	109.8	108.8

MOISTURE - DENSITY TEST NO. 1A

Material - Barrier Silt October 10th, 1946.- Date Tested

	Trial #1	Trial #2	Trial #3	Trial #4
Wt. Cylinder + Wet Soil g.	943.6	966.8	1001.1	983.5
Wt. Cylinder g.	226.6	226.6	226.6	226.6
Wt. Wet Soil g.	717.0	740.2	774.5	756.9
Wt. Tare g.	462.5	430.3	464.0	407.3
Wt. Tare + Dry Soil g.	1115.2	1092.4	1134.5	1050.0
Wt. Dry Soil g.	652.7	662.1	670.5	642.7
Wt. Water g.	64.3	78.1	104.0	114.2
% Water	9.85	11.8	15.5	17.8
Dry Density #/cu.ft.	106.0	107.8	109.1	104.5
Method of Compaction	15 blows - 4 layers - small cylinder with 5.5 rammer.			

MOISTURE - DENSITY TEST #2

Material - Barrier Silt + 2% Liquor   Date Tested - October 11th, 1946.

	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6	Trial #7
Wt. Cylinder + Wet Soil	981.45	983.85	940.20	925.90	976.65	881.4	953.2
Wt. Cylinder	226.67	226.67	226.67	226.67	226.67	226.67	226.67
Wt. Wet Cylinder	754.78	757.18	713.53	699.23	749.98	654.7	726.5
Wt. Dry Soil + Tare	1150.7	1144.0	1089.6	789.3	1124.2	1015.0	1138.0
Wt. Tare	470.4	469.6	463.0	182.7	462.2	462.2	465.0
Wt. Dry Soil	680.3	674.4	626.6	606.6	662.0	552.8	673.0
Wt. Water	74.5	82.8	86.9	92.6	88.0	101.9	53.5
% Moisture	11.0	12.3	13.9	15.3	13.3	18.4	7.9
Dry Density #/cu.ft.	111.0	110.0	102.2	99.0	108.0	90.2	109.8
Water Approx. %	12	14	16	18	15	20	9

Method of Compaction   15 blows - 4 layers - small cylinder with 5.5 lb. rammer

MOISTURE - DENSITY TEST #3

Material - Barrier Silt + 4% Liquor   Date Tested - October 12th, 1946.

	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5
Wt. Cylinder + Wet Soil	990.35	923.6	887.8	955.0	982.5
Wt. Cylinder	226.67	226.67	226.67	226.67	226.67
Wt. Wet Soil	763.68	696.93	661.13	728.3	755.8
Wt. Dry Soil + Tare	946.6	1071.0	1035.8	1144.0	1130.7
Wt. Tare	257.75	462;2	466.6	470.4	461.3
Wt. Dry Soil	689.3	608.8	568.3	673.6	669.4
Wt. Water	74.4	88.1	92.8	54.7	86.4
% Moisture	10.8	14.5	16.3	8.1	12.9
Dry Density #/cu.ft.	112.5	99.3	92.7	109.9	109.2
Water Approx. %	12	16	18	28	14

Method of Compaction   15 blows - 4 layers - small cylinder with 5.5 lb. rammer

MOISTURE - DENSITY TEST #4

Material - Barrier Silt + 10% Liquor　　Date Tested - October 13th, 1946.

	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5
Wt. Cylinder + Wet Soil	1008.65	994.40	945.25	902.8	986.85
Wt. Cylinder	226.67	226.67	226.67	226.67	226.67
Wt. Wet Soil	781.98	767.73	718.68	676.13	760.18
Wt. Tare + Dry Soil	1179.0	836.8	1097.6	733.7	1164.6
Wt. Tare	466.6	148.6	465.0	148.8	461.25
Wt. Dry Soil	712.4	688.2	632.6	584.9	703.4
Wt. Water	69.6	79.5	86.1	91.2	56.8
% Moisture	9.8	11.6	13.6	15.6	8.1
Dry Density	116.2	112.3	103.2	95.5	114.8
Water Approx. %	12	14	16	18	10

Method of Compaction　15 blows - 4 layers - small cylinder with 5.5 lb. rammer

BLOWS - DENSITY RELATIONS

Material - Barrier Silt

Vol. of Cylinder #1 - 1/74 cu.ft.

Date Tested - October 10th, 1946.

Wt. of Cylinder #1 - 226.67 gms.

	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6
No. of Blows	10	12	14	16	14	18
Wt. Cylinder + Wet soil g	979.2	992.9	997.9	999.6	1002.8	1005.7
Wt. Wet Soil g.	752.5	766.1	771.2	772.9	776.2	779.1
Wt. Dry Soil + Tare g.	807.4	1131.0	1137.6	1136.6	825.0	1143.7
Wt. Tare g.	148.4	464.5	468.9	462.9	148.4	464.5
Wt. Dry Soil g.	659.0	666.0	668.8	673.7	676.6	679.2
Wt. Water g.	93.5	99.7	102.5	99.2	99.6	99.8
Moisture Content %	14.20	14.95	15.35	14.72	14.72	14.72
Dry Density #/cu.ft.	107.5	108.9	109.1	110.0	110.4	110.8
Method of Compaction	4 layers - small cylinder - 5.5 lb. rammer with varying number of blows.					

ST NO. 1

FREEZING TEST DATA

		Specimen No.			1		2		3		4		5		6	
Day	Date	Temperature Room °c	Temperature Water °c	Degree Hours	Rdg.	Heave %	Rdg.	Heave %	Rdg.	Heave %	Rdg.	Heave %	Rdg.	Heave %	Rdg.	Heave %
1	Dec. 24	-9	+17.4	0	0	0	0	0	0	0	0	0	0	0	0	0
2	25	-9	17.4	216	0.1	1.7	0	0	0	0	0	0	0	0	0	0
3	26	-9	17.0	432	0.25	4.2	0	0	0	0	0	0	0	0	0	0
4	27	-9	16.4	648	0.50	8.3	0	0	0	0	0	0	0	0	0	0
5	28	-9	14	864												
6	29	-9.7	10	1097	0.50	8.3	0	0	0	0	0	0	0	0	0	0
7	30	-9.7	10	1330												
8	31	-9.7	9.3	1563	0.50	8.3	0	0	0	0	0	0	0	0	0	0
9	Jan. 1	-9.7	5	1796												
10	2	-10	0	2036			0	0	0	0	0	0	0	0	0	0
11	3	-11	0	2300	0.50	8.3	0.13	2.2	0.09	1.5	0.05	0.8	0.02	0.3	0	0
12	4	-11	6.5	2564	0.57	9.5	0.16	2.7	0.09	1.5	0.05	0.8	0.02	0.3	0	0
13	5	-12	9.5	2852	0.60	10.0	0.20	3.3	0.11	1.8	0.05	0.8	0.02	0.3	0	0
14	6	-12	10	3140	0.64	10.7	0.23	3.8	0.14	2.3	0.05	0.8	0.02	0.3	0	0
15	7	-13	10	3452	0.66	11.0	0.26	4.3	0.14	2.3	0.05	0.8	0.02	0.3	0	0
16	8	-26	10	4076	0.68	11.3	0.31	5.2	0.14	2.3	0.05	0.8	0.02	0.3	0	0
17	9	-29	10	4772	0.76	12.6	0.39	6.5	0.14	2.3	0.05	0.8	0.02	0.3	0	0
18	10	-29	10	5468	0.84	14.0	0.47	7.8	0.21	3.5	0.14	2.3	0.04	0.7	0	0
19	11	-30	10	6164												
20	12	-31	10	6908												
21	13	-31	9	7654	0.84	14.0	0.64	10.6	0.22	3.6	0.16	2.7	0.04	0.7	0	0
22	14	-31	8	8400												
23	15	-31	7	9146												
24	16	-30	5	9788	1.20	20.0	0.90	15	0.62	10.0	0.20	3.3	0.04	0.7	0	0

SET. NO. 1

FREEZING TEST DATA

SPECIMEN NO.	1	2	3	4	5	6
Cylinder Data						
Cylinder Number	1	2	3	4	5	6
Cylinder Diameter ins.	2.22	2.22	2.22	2.22	2.22	2.22
Cylinder Height ins.	6.01	6.00	6.03	6.01	6.01	5.99
Cylinder Volume cu.ft.	1/74	1/74	1/74	1/74	1/74	1.74
Cylinder Weight gms.	226.7	228.1	230.2	225.8	224.9	223.0

Composition of Mix	%	gms.	%	gms.	%	gms.	%	gms.	%	gms.	%	gms.
Soil		750		750		750		750		750		750
Admixture	0	0	1	7.5	2	15	4	30	7	52.5	10	75
Water	14.5	109.0	12.0	86.0	12	82.5	12.5	81.0	12	64.0	12	53.5

	1	2	3	4	5	6
Wt. Sample + Cylinder Start g.	1001.4	978.2	986.7	996.8	978.7	939.8
Wt. Sample Start g.	774.7	750.1	756.5	771.0	753.8	716.8
Wt. Sample + Tare End g.	1318.5	1321.4	1286.0	1267.0	1245.0	1213.4
Wt. Dry Sample + Tare g.	1136.3	1128.6	1142.2	1148.0	1141.3	1123.8
Wt. Tare g.	461.3	463.4	470.1	462.3	463.5	463.9
Wt. Sample End g.	857.2	858.0	815.9	804.7	781.5	749.5
Wt. Dry Sample g.	675.0	665.2	672.1	685.7	677.8	659.9
Wt. Moisture Start g.	99.7	84.9	84.4	85.3	76.0	56.9
Wt. Moisture End g.	196.3	192.8	143.8	119.0	103.7	89.6
Moisture Start %	14.8	12.7	12.5	12.4	11.2	8.6
Moisture End %	29.7	29.0	21.4	17.3	15.3	13.5
Initial Degree Saturation %	73	62	61	65	56	41
Final Degree Saturation %	93	99	81	82	75	64
Initial Dry Density lbs/cu.ft.	107.8	108.3	109.3	111.8	110.3	107.5
Specific Gravity Soil	2.74	2.74	2.74	2.74	2.74	2.74
Distance to Frozen Soil from Bottom of Cylinder ins.	0	0	0.35	0.8	1.25	-
Total Heave %	20.0	15.0	10.0	3.3	0.7	0
Air Temperature Start Heave °c	- 9°	-11°	-11°	-11°	-11°	-

Remarks - Humidity of refrigerator was very low so that final moisture contents are low. This applies particularly to specimen No. 1.

FREEZING TEST DATA

		Specimen No.			7			8			9			10			11			12	
		Temperature		Degree		Net	Heave		Net	Heave		Net	Heave		Net	Heave		Net	Heave		Net	Hea
Day	Date	Room°c	Water°c	Hours	Rdg.	Rdg.	%	Rdg.	Rdg.	%	Rdg.	Rdg.	%	Rdg.	Rdg.	%	Rdg.	Rdg.	%	Rdg.	Rdg.	%
1	Jan.28	-10	+14	0	6.00	0	0	6.18	0	0	6.11	0	0	6.20	0	0	6.17	0	0	6.20	0	0
2	29	-10	+16	240																		
3	30	-10	+18	480	6.00	0	0	6.18	0	0	6.11	0	0	6.20	0	0	6.17	0	0	6.20	0	0
4	31	-12	+19	720																		
5	Feb. 1	-14	+19	1008																		
6	2	-14	+19	1344	5.88	.12	2	6.18	0	0	6.10	.01	.2	6.20	0	0	6.17	0	0	6.20	0	0
7	3	-15	+19	1680																		
8	4	-15	+19	2040	5.64	.36	6.0	6.18	0	0	6.04	.07	1.2	6.18	.02	.3	6.17	0	0	6.20	0	0
9	5	-20	+19	2400	5.12	.88	14.6	6.18	0	0	6.01	.10	1.7	6.18	.02	.3	6.17	0	0	6.20	0	0
10	6	-20	+18	2880	4.83	1.17	19.5	5.99	.19	3.2	5.86	.25	4.1				6.17	0	0			
11	7	-25	+15	3360																		
12	8	-30	+12	3960	4.45	1.55	25.8	5.94	.24	4.0	5.82	.29	4.8	6.17	.03	.5	6.17	0	0	6.20	0	0
13	9	-30	+11	4680																		
14	10	-31	+10	5400	4.15	1.85	30.8	5.94	.24	4.0	5.77	.34	5.6	6.17	.03	.5	6.17	0	0	6.20	0	0
15	11	-30	+ 9	6148																		
16	12	-30	+ 8	6868																		
17	13	-30	+ 6	7588	3.89	2.11	35.1	5.59	.59	9.8	5.63	.48	8.0	6.16	.04	.7	6.17	0	0	6.20	0	0
18	14	-30	+ 5	8308																		
19	15	-30	+ 4	9028																		
20	16	-30	+ 4	9748																		
21	17	-30	+ 3.5	10468	3.80	2.20	36.6	5.57	.61	10.3	5.60	.51	8.5	6.16	.04	.7	6.17	0	0	6.20	0	0

SET NO. 2 FREEZING TEST DATA

SPECIMEN NO.	7		8		9		10		11		12	
CYLINDER DATA												
Cylinder Number	1		2		3		4		5		6	
Cylinder Diameter ins.	2.22		2.22		2.22		2.22		2.22		2.22	
Cylinder Height ins.	6.01		6.00		6.03		6.01		6.01		5.99	
Cylinder Volume cu.ft.	1/74		1/74		1/74		1/74		1/74		1/74	
Cylinder Weight g.	226.7		228.1		230.2		225.8		224.9		223.0	
Composition of Mix	%	gms.	%	gms.	%	gms.	%	gms.	%	gms.	%	gms.
Soil		750		750		750		750		750		750
Admixture	0	0	1	7.5	2	15	4	30	7	52.5	10	75
Water	14.5	109.0	12	86.0	12	82.5	12.5	81.0	12	64.0	12	53.5
Wt.Sample + Cylinder Start g.	998.8		985.7		990.5		1007.0		1013.0		990.9	
Moisture Content %	14.8		12.7		12.5		12.4		11.2		8.6	
Wt. Sample at Start g.	772.1		757.6		760.3		781.2		788.1		767.9	
Dry Wt. Sample g.	672.0		673.0		676.0		694.0		707.0		707.0	
Initial Dry Density lbs./cu.ft.	109.8		109.9		110.2		113.1		115.3		115.3	
Initial Degree Saturation %	73		64		63		67		64		50	
Wt.Partial Sample + Tare End g.	1054.0		1015.0		1203.0		1224.0		1252.9		1230.0	
Wt. Tare g.	469.9		257.5		463.1		449.3		461.1		462.3	
Wt. Dry Sample + Tare g.	898.7		867.1		1066.5		1069.4		1153.8		1141.6	
Wt. Dry Sample g.	428.8		609.6		603.4		620.1		692.7		679.3	
Wt. Water g.	155.3		147.9		136.5		154.6		99.1		98.4	
% Moisture	36.2		24.2		22.6		24.9		14.3		14.5	
Specific Gravity Soil	2.74		2 74		2.74		2 74		2.74		2.74	
Distance to Frozen Soil from Bottom of Cylinder ins.	1.38		1.63		1.76		-		-		-	
Total Heave %	36.6		10.3		8.5		0.7		0		0	
Air Temp. Start Heave °c	-14		-20		-15		-15		-		-	

Remarks - Part of the soil in each specimen was lost while removing from box. Initial moisture contents are assumed.

ATTERBERG LIMITS

Material - Barrier Silt Date Tested - January 16th, 1947.

LIQUID LIMIT	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5
No. of Blows	35	37	9	10	$13\frac{1}{2}$
Container Plus Wet Sample	28.5830	27.6217	31.4298	36.3790	41.8625
Container Plus Dry Sample	27.0709	26.3097	29.2980	33.7490	38.0001
Container Weight	18.7546	18.8409	18.6756	21.0060	18.9595
Weight of Moisture	1.5121	1.3120	2.1318	2.6300	3.8624
Weight of Dry Soil	8.3163	7.4678	10.6224	12.7430	19.0406
% Moisture	18.2	17.6	20.1	20.6	20.3

PLASTIC LIMIT - Unable to determine - assume equal to liquid limits.

PLASTICITY INDEX = **liquid limit minus** plastic limit = 0

ATTERBERG LIMITS

Material - Barrier Silt + 10% Liquor   Date Tested - January 16th, 1947.

LIQUID LIMIT	Trial #1	Trial #2	Trial #3	Trial #4
No. of Blows	33	44	17½	9
Container Plus Wet Sample	30.0463	32.2305	35.0392	33.5405
Container Plus Dry Sample	28.4990	30.3946	32.7088	31.3165
Container Weight	18.9310	18.9595	19.3696	19.4643
Weight of Moisture	1.5473	1.8359	2.3304	2.2240
Weight of Dry Soil	9.5680	11.4351	13.3392	11.8522
% Moisture	16.2	16.0	17.5	18.7

PLASTIC LIMIT - Unable to determine - assume equal to liquid limits.

PLASTICITY INDEX - = liquid limit minus plastic limit = 0

CONSOLIDATION TEST

January 9th, 1947.

Sample	Barrier Silt	
Mach.Mult.	100	
Wt. R+S+W (Start)	1097.50	gms.
Wt. R+S+W (End)	1098.72	gms.
Wt. T+S	200.28	gms.
Wt. T	87.85	gms.
S	112.43	gms.
W% Start	14.5	
W% End	15.6	
H_s	0.636	in.
S_s	2.74	
e (Start)	0.587	

Ring #8 Data

Wt.	968.75	gms.
A.	3.94	sq. in.
Thick.	1.01	in.
Vol.	3.98	cu.in.

Wt.

Block)
Stone) 354.6 gms.
Ball)
= 3.5 gms. on pan

Time	Dial in.	e	Unit Pressure p.s.i.
	10 gms.		
o	.9090		
6 s	-		
10 s	-		
15 s	.9084		
30 s	.9083		
1 m	.9083		
Water Bottom			
2 m	.9077		
4 m	.9077		
8 m	.9077		
15 m	.9069		
30 m	.9069		
115 m	.9069		
18 h	.9068	0.585	0.616
	50 gms.		
6 s	.8995		
10 s	.8987		
15 s	.8985		
30 s	.8982		
1 m	.8978		
2 m	.8976		
4 m	.8973		
8 m	.8972		
15 m	.8971	0.570	2.41
	100 gms.		
6 s	.8895		
10 s	.8892		
15 s	.8890		
30 s	.8887		
	100 gms. (cont'd)		
1 m	.8884		
2 m	.8881		
4 m	.8880		
8 m	.8878		
15 m	.8876		
30 m	.8874		
66 m	.8871		
367 m	.8870		
48.5 h	.8852	0.555	4.64
	500 gms.		
2 s	.8700		
6 s	-		
10 s	.8621		
15 s	.8675		
30 s	.8673		
1 m	.8670		
2 m	.8669		
4 m	.8668		
8 m	.8663		
15 m	.8661		
30 m	.8660		
63 m	.8658		
126 m	.8657	0.520	22.5
	2000 gms.		
2 s	.8644		
4 s	.8559		
6 s	.8553		
8 s	.8528		
10 s	.8524		

Consolidation Test - Barrier Silt (Page 2)

Time	Dial in.	e	Unit Pressure p.s.i.
	2000 gms. (cont'd)		
12 s	.8522		
14 s	.8520		
30 s	.8518		
1 m	.8514		
2 m	.8512		
4 m	.8509		
8 m	.8507		
15 m	.8505	0.495	89.6

Permeability Data
(For 2000 gm. load)

$a_v = 45 \times 10^{-5} \ \frac{\text{sq.in.}}{\text{lbs.}}$

$t = 6.0$ s

$e_m = 0.507$

$H = 0.48$ in

$T = 0.845$

$K = 0.93 \times 10^{-6} \ \frac{\text{cm.}}{\text{sec.}}$

CONSOLIDATION TEST

January 7th, 1947.

Sample	Barrier Silt	Ring Data	
Mach.Mult.	80		
Wt. R+S+W (Start)	1098.36 gms.	Wt.	986.60 gms.
Wt. R+S+W (End)	1098.90 gms.	A.	3.94 sq. in.
Wt. R+S	1081.98 gms.	Diam.	2.24 in.
S	113.38 gms.	Thick.	1.01 in.
W% (Start)	14.4 %	Vol.	3.98 cu.in.
W% (End)	14.9 %		
		Wt.	
H_s	0.64 in.	Block)	
S_s	2.74	Stone)	302 gms.
e (Start)	0.579	Ball)	
		=	3.77 gms. on pan

Time	Dial in.	e	Unit Pressure p.s.i.	Time	Dial in.	e	Unit Pressure p.s.i.
	10 gms.				200 gms.		
0	.8757	0.579		2 s	.8682		
6 s	.8705			4 s	.8680		
15 s	.8704			6 s	.8679		
30 s	.8704			8 s	.8678		
1 m	.8704			10 s	.8677		
Water	Bottom			12 s	.8676		
2 m	.8706			15 s	.8676		
4 m	.8707			20 s	.8675		
Water	Top			30 s	.8675		
8 m	.8710			1 m	.8674		
15 m	.8712	0.571	0.616	2 m	.8673	0.565	9.12
	50 gms.				1000 gms.		
2 s	.8704			1 s	.8610		
4 s	.8703			2 s	.8602		
6 s	.8702			4 s	.8594		
8 s	.8702			6 s	.8591		
10 s	.8702			8 s	.8590		
12 s	.8702			10 s	.8589		
15 s	.8702			12 s	.8588		
20 s	.8702			15 s	.8588		
30 s	.8702			20 s	.8585		
1 m	.8702			30 s	.8583		
2 m	.8702	0.570	2.41	1 m	.8582		

Consolidation Test - Barrier Silt (Page 2)

Time	Dial in.	e	Unit Pressure p.s.i.
	1000 gms. (cont'd)		
2 m	.8581	0.561	45.05
4 m	.8581		
8 m	.8580		
15 m	.8579		
30 m	.8578	0.550	45.05
	4082 gms.		
2 s	.8498	0.538	
4 s	.8480		
6 s	.8460		
8 s	.8450		
10 s	.8445		
12 s	.8443		
15 s	.8442		
20 s	.8441		
30 s	.8440		
1 m	.8438		
2 m	.8435	0.528	183
4 m	.8432		
12.5m	.8425	0.526	
15 m	.8423		

Permeability Data
(For 4082 gm. load)

$a_v = 17.9 \times 10^{-5} \frac{\text{sq.in.}}{\text{lb.}}$

$T = 0.845$

$t = 6.4$ s

$e_m = 0.538$

$H = 0.49$ in.

$K = 0.34 \times 10^{-6} \frac{\text{cm}}{\text{sec.}}$

CONSOLIDATION TEST

January 10th, 1947.

Sample	Barrier Silt+10% Liquor
Mach.Mult.	50
Wt. R+S+W (Start)	1087.30 gms.
Wt. R+S+W (End)	1086.22 gms.
Wt. T+S	211.28 gms.
Wt. W+T	97.81 gms.
S	113.47 gms.
W% Start	18.6 %
W% End	17.6 %
H_s	0.645 in.
S_s	2.74
e (Start)	0.566

Ring Data #9

Wt.	952.75	gms.
A	3.94	sq. in.
Thick.	1.01	in.
Vol.	3.98	cu.in.
Wt. Block) Stone) Ball)	375	gms.
=	75 gms.	on pan

Time	Dial	e	Unit Pressure p.s.i.
	10 gms.		
0	.9844		
6 s	.9844		
1 m	.9843	0.566	0.49
	50 gms.		
2 s	.9841		
6 s	.9841		
1 m	.9841	0.566	1.61
	200 gms.		
2 s	.9838		
4 s	.9822		
6 s	.9820		
8 s	.9819		
10 s	.9819		
12 s	.9819		
15 s	.9818		
30 s	.9818	0.562	5.80
	1000 gms.		
2 s	.9712		
4 s	.9708		
6 s	.9706		
8 s	.9706		
10 s	.9706		
	1000 gms. (cont'd)		
12 s	.9705		
15 s	.9705		
30 s	.9703		
1 m	.9702		
2 m	.9699		
4 m	.9694	0.543	28.20
	4000 gms.		
2 s	.9620		
4 s	.9555		
6 s	.9524		
8 s	.9520		
10 s	.9519		
12 s	.9518		
15 s	.9517	e_m= 0.527	
30 s	.9515		
1 m	.9511		
2 m	.9504		
4 m	.9499		
8 m	.9494		
15 m	.9489	0.512	112.3

Permeability Data
(For 4000 gm. load)

a_v = $38.8 \times 10^{-5}\ \frac{\text{sq.in.}}{\text{lb.}}$

t = 4.7 s

e_m = 0.527

H = 0.49 in.

K = $1.01 \times 10^{-6}\ \frac{\text{cm.}}{\text{sec.}}$

Triaxial Compression Test

Mach. Mult.	50 : 1			
Soil Sample	Barrier	Silt		
Wt. Samp. Tube	223.00	225.84	225.84	gms.
Diam. Samp. Tube	2.22	2.22	2.22	in.
Area Samp. Tube	3.869	3.869	3.869	sq.in.
Length Sample	5.99	6.01	6.01	in.
Wt. Loading Block) Wt. Piston)	586	586	586	gms.
S_s	2.74			

	T.C.1	T.C.2	T.C.3	
Lateral Pressure	0 #	20 #	35 #	
Wt. Tube+ S + W at Start	998.85	1001.35	999.68	gms.
S + W at Start	775.85	775.51	773.84	gms.
S + W + Dish at End	1227.4	1227.4	1234.3	gms.
Wt. Dish	461.3	463.4	462.3	gms.
Wt. S + Dish	1132.7	-	1140.8	gms.
Wt. S	671.4	671.02	678.5	gms.
W% at Start	15.6	15.6	14.1	%
W% at End	14.1	13.9	13.8	%
Unit Weight	110.4	109.9	111.2	gms.

T.C. 1

Load gms.	Dial in.	Strain %	Area sq.in.	Vert. Stress kg/cm²
0	.9655	-	24.96	.02
20	.9648	.012	24.96	.06
50	.9618	.06	24.97	.12
100	.9452	.34	25.05	.22
150	.9320	.56	25.10	.32
200	.9211	.74	25.15	.42
250	.9105	.92	25.19	.52
300	.9030	1.04	25.22	.62
350	.8961	1.15	25.25	.72
400	.8861	1.32	25.29	.81
450	.8758	1.49	25.34	.91
500	.8628	1.71	25.39	1.01

T.C. 2

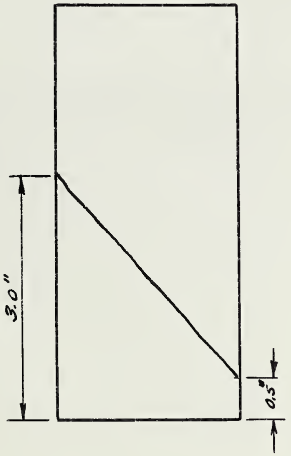
Load gms.	Dial in.	Strain %	Area sq. in.	Vert. Stress kg/cm²
0	.9788	-	24.96	1.43
50	.9683	.17	25.00	1.53
100	.9655	.22	25.02	4.63
150	.9610	.30	25.04	1.73
200	.9594	.32	25.04	1.83
250	.9584	.34	25.05	1.93
300	.9578	.35	25.05	2.03
350	.9568	.37	25.05	2.13
400	.9558	.38	25.06	2.23
450	.9549	.40	25.06	2.33
500	.9541	.41	25.06	2.43
550	.9532	.43	25.07	2.53

T.C. 3

Load gms.	Dial in.	Strain %	Area sq.in.	Vert. Stress kg/cm²
0	.9901	-	24.96	2.48
50	.9874	.04	24.97	2.58
100	.9861	.06	24.97	2.68
200	.9813	.15	25.00	2.88
300	.9861	.23	25.02	3.08
400	.9742	.26	25.03	3.28
454	.9738	.27	25.03	3.39
554	.9728	.29	25.03	3.59
654	.9717	.31	25.04	3.79
754	.9705	.33	25.04	3.99
854	.9693	.35	25.05	4.19
954	.9682	.37	25.05	4.39

Triaxial Compression Test - Barrier Silt (Page 2)

T.C. 1					T.C. 2					T.C. 3				
Load	Dial	Strain	Area	Vert. Stress	Load	Dial	Strain	Area	Vert. Stress	Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.in.	kg/cm^2	gms.	in.	%	sq.in.	kg/cm^2	gms.	in.	%	sq.in.	kg/cm^2
520	Failed				600	.9522	.44	25.07	2.63	1054	.9670	.38	25.06	4.59
					650	.9512	.46	25.08	2.73	1154	.9658	.40	25.06	4.79
					700	.9502	.48	25.08	2.83	1367	.9631	.45	25.07	5.21
					750	.9490	.50	25.09	2.93	1567	.9603	.50	25.09	5.60
					800	.9483	.51	25.09	3.03	1767	.9577	.54	25.10	6.00
					850	.9468	.53	25.09	3.13	1967	.9552	.58	25.11	6.40
					900	.9459	.55	25.10	3.23	2167	.9522	.63	25.12	6.80
					950	.9448	.57	25.10	3.33	2367	.9498	.67	25.13	7.19
					1000	.9438	.58	25.11	3.43	2567	.9468	.72	25.14	7.59
					1050	.9426	.60	25.11	3.52	2767	.9438	.77	25.15	7.99
					1100	.9418	.62	25.12	3.62	2967	.9408	.82	25.17	8.38
					1150	.9406	.64	25.12	3.72	3167	.9375	.87	25.18	8.77
					1200	.9398	.65	25.12	3.82	3367	.9348	.92	25.19	9.16
					1250	.9385	.67	25.13	3.92	3567	.9301	1.00	25.21	9.56
					1300	.9376	.69	25.13	4.02	3767	.9255	1.07	25.23	9.95
					1350	.9365	.70	25.14	4.12	3967	.9208	1.15	25.25	10.34
					1400	.9355	.72	25.14	4.22	4167	.9146	1.25	25.28	10.73
					1450	.9347	.73	25.14	4.32	4267	.9108	1.32	25.29	10.92
					1500	.9332	.76	25.15	4.42	4367	.9068	1.38	25.31	11.11
					1550	.9321	.78	25.16	4.52	4467	.9020	1.46	25.33	11.30
					1600	.9310	.80	25.16	4.61	4567	.8984	1.52	25.35	11.49
					1650	.9298	.82	25.17	4.71	4667	.8936	1.60	25.37	11.68
					1700	.9286	.84	25.17	4.81	4767	.8872	1.71	25.39	11.87
					1750	.9274	.86	25.18	4.91	4867	.8790	1.85	25.43	12.05
					1800	.9263	.87	25.18	5.01	4917	.8678	2.03	25.48	12.13



Triaxial Compression Test - Barrier Silt (Page 3)

T.C. 1

T.C. 2

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.in.	kg/cm^2
1850	.9251	.89	25.18	5.11
1900	.9238	.91	25.19	5.21
1950	.9228	.94	25.20	5.30
2000	.9214	.95	25.20	5.40
2050	.9199	.97	25.20	5.50
2100	.9184	1.00	25.21	5.60
2150	.9170	1.03	25.22	5.70
2200	.9153	1.05	25.22	5.80
2250	.9137	1.08	25.23	5.89
2300	.9118	1.11	25.24	5.99
2350	.9100	1.14	25.25	6.09
2400	.9076	1.18	25.25	6.19
2450	.9056	1.22	25.27	6.29
2500	.9040	1.24	25.27	6.38
2550	.9028	1.26	25.28	6.48
2600	.9011	1.29	25.29	6.57
2650	.8998	1.31	25.29	6.67
2700	.8978	1.35	25.30	6.77
2750	.8958	1.39	25.31	6.86
2800	.8936	1.42	25.32	6.86
2850	.8901	1.47	25.33	7.06
2900	.8870	1.52	25.35	7.15
2950	.8823	1.60	25.37	7.25
3000	.8748	1.73	25.40	7.34
3050	.8664	1.87	25.44	7.43

T.C. 3

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.in.	kg/cm^2
4967	.8564	2.22	25.53	12.21
5017	Failure			

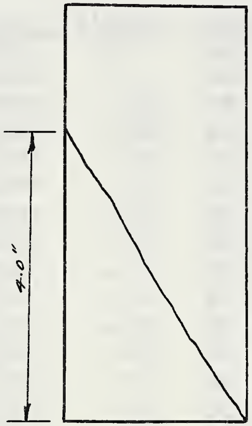
See
FIG. 20.

SAMPLE
ON RIGHT

Triaxial Compression Test - Barrier Silt (Page 4)

T.C. 2

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.in.	kg/cm^2
3100	.8550	2.06	25.48	7.52
3150	.8282	2.50	25.60	7.59
3200	Failure			



Triaxial Compression Test

Mach. Mult.	50 : 1			
Soil Sample	Barrier	Silt+4%	Liquor	
Wt. Samp. Tube	225.84	226.67	223.00	gms.
Diam. Samp. Tube	2.22	2.22	2.22	in.
Area Samp. Tube	3.869	3.869	3.869	sq.in.
Length Sample	6.01	6.01	5.99	
Wt. Loading Block) Wt. Piston)	586	586	586	gms.
S_s	2.74			

	T.C. 1	T.C. 2	T.C. 3	
Lateral Pressure	0 #	20 #	35 #	
Wt. Tube + S + W at Start	1007.85	1006.50	1003.81	gms
S + W at Start	782.01	779.83	780.81	gms
S + W + Dish at end	1234.2	1238.0	1231.2	gms
Wt. Dish	461.3	463.4	462.3	gms
Wt. S + Dish	1151.0	1155.1	1150.2	gms
Wt. S	689.7	691.7	687.9	gms
W% at Start	13.4%	12.7	13.5	%
W% at end	12.1	12.0	11.8	%
Unit Wt.	113.0	113.3	112.7	gms

T.C. 1

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.cm.	kg/cm²
0	.8067	-	24.96	.02
50	.7841	.38	25.06	.12
100	.7754	.52	25.09	.22
150	.7656	.68	25.13	.32
170	.7620	.74	25.15	.36
190	.7588	.80	25.16	.40
210	.7560	.84	25.17	.44
230	.7532	.89	25.18	.48
250	.7499	.95	25.20	.52
300	.7432	1.06	25.23	.52
350	.7364	1.17	25.26	.72
400	.7300	1.28	25.28	.81
450	.7198	1.45	25.33	.91
500	.7052	1.69	25.39	1.01

T.C. 2

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.cm.	kg/cm²
0	.9986	-	24.96	1.43
50	.9984	.003	24.96	1.53
100	.9980	.010	24.96	1.63
200	.9930	.093	24.98	1.83
400	.9890	.16	25.00	2.23
600	.9856	.22	25.02	2.63
800	.9820	.28	25.03	3.03
913	.9802	.31	25.04	3.26
1367	.9711	.46	25.08	4.16
1567	.9668	.53	25.09	4.56
1767	.9625	.60	25.11	4.95
1967	.9582	.67	25.13	5.35
2167	.9540	.74	25.15	5.74
2367	.9493	.82	25.17	6.14

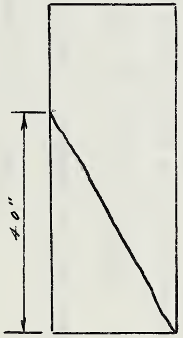
T.C. 3

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.cm.	kg/cm²
0	.9508	-	24.96	2.48
20	.9509	-	24.96	2.52
40	.9509	-	24.96	2.56
100	.9503	.008	24.96	2.68
200	.9480	.05	24.97	2.88
400	.9378	.22	25.02	3.28
600	.9277	.39	25.06	3.68
913	.9242	.44	25.07	4.31
1367	.9178	.55	25.10	5.21
1667	.9132	.63	25.12	5.80
1967	.9092	.69	25.13	6.40
2267	.9044	.77	25.15	6.79
2567	.9002	.84	25.17	7.58
2867	.8942	.94	25.20	8.37

Triaxial Compression Test - Barrier Silt + 4% Liquor (Page 2)

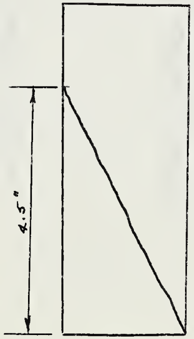
T.C. 1

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.cm.	kg/cm^2
520	.6894	1.95	25.46	1.04
540	Failed			



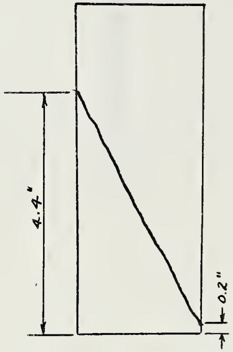
T.C. 2

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.cm.	kg/cm^2
2567	.9441	.91	25.19	6.53
2667	.9406	.97	25.20	6.73
2767	.9370	1.02	25.22	6.92
2867	.9325	1.10	25.24	7.11
2967	.9278	1.18	25.26	7.31
3017	.9225	1.27	25.28	7.40
3067	.9198	1.31	25.29	7.50
3117	.9153	1.39	25.31	7.59
3167	.9108	1.46	25.33	7.69
3217	.9052	1.55	25.35	7.78
3267	.8980	1.67	25.38	7.87
3317	.8890	1.82	25.92	7.96
3337	.8770	2.02	25.47	7.98
3357	.8586	2.33	25.56	8.00
Failed				



T.C. 3

Load	Dial	Strain	Area	Vert. Stress
gms.	in.	%	sq.cm.	kg/cm^2
3067	.8903	1.01	25.21	8.77
3267	.8860	1.08	25.23	8.96
3467	.8816	1.16	25.25	9.55
3667	.8771	1.23	25.27	9.94
3867	.8731	1.30	25.29	10.13
4067	.8662	1.41	25.32	10.51
4267	.8594	1.53	25.35	10.90
4467	.8515	1.66	25.38	11.28
4667	.8418	1.82	25.42	11.66
4767	.8328	1.97	25.46	11.85
4867	.8235	2.13	25.50	12.03
4967	.8128	2.30	25,55	12.20
5067	.7960	2.58	25.62	12.37
5117	.7702	3.01	25.73	12.43
5137	.7280	3.72	25.92	12.39
Failed				



VI

RESULTS

The experimental results will be presented in the same order as the data.

1. Grain Size - see Figure 5.

The material was found to be a silt with the following grain size distribution:

15% finer than 0.005 mm. (clay)

65% finer than 0.05 mm. and coarser than 0.005 mm. (silt)

20% coarser than 0.05 mm. (sand)

34% finer than 0.02 mm.

The slope of the curve indicates a fairly uniform soil.

2. Specific Gravity Determination

The specific gravity of the solids was determined to be 2.74.

3. Density Tests - See Figure 2.

(a) The standard proctor density of the silt was determined to be 110 #/cu.ft. at a moisture content of 14.5%.

(b) With increasing amount of admixture, the standard density increased and the optimum moisture content decreased. Hogentogler(8) reports similar results.

(c) Silt compacted at 14.5% moisture, but with from two to ten per cent admixture, showed a decrease in density of approximately fifteen per cent.

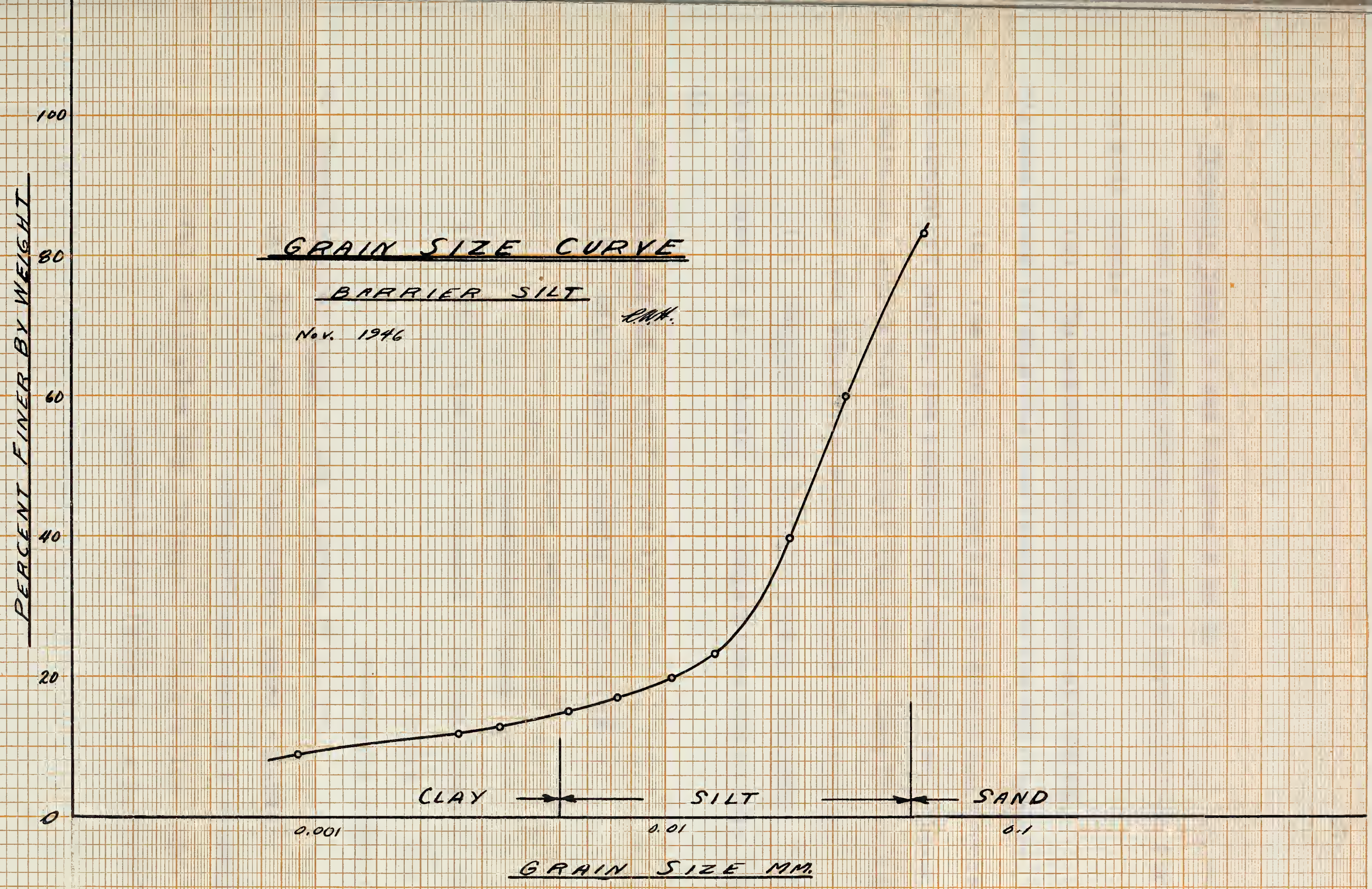
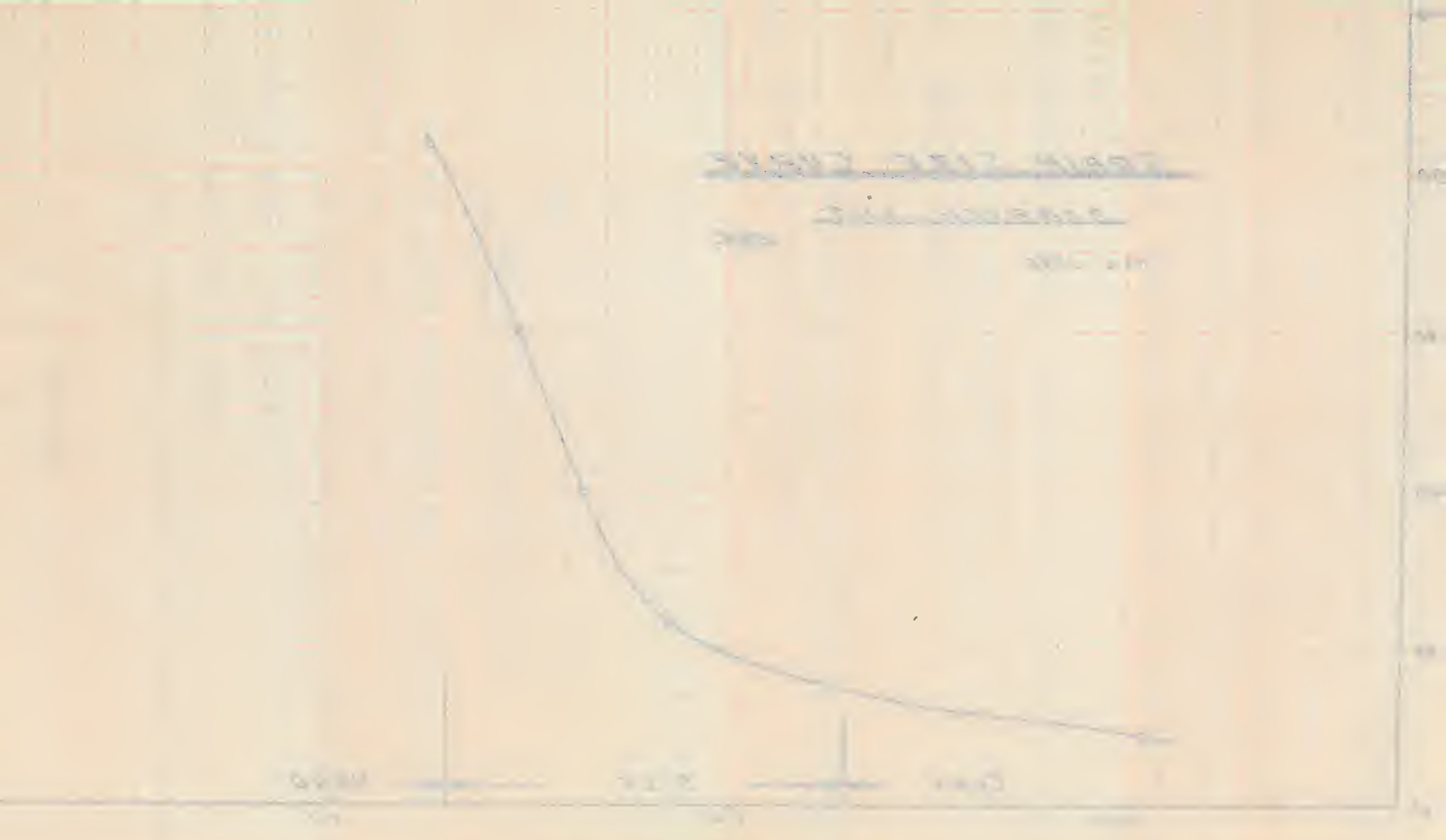

GRAIN SIZE CURVE
BARRIER SILT
Nov. 1946
PERCENT FINER BY WEIGHT
100
80
60
40
20
0
CLAY
SILT
SAND
0.001
0.01
0.1
GRAIN SIZE MM.

FIGURE 5



4. Freezing Tests - see Figures 6 to 10

The following general results were obtained for the silt used:-

(a) The maximum heave recorded was 36.6%. Figures 9 and 10 show the ice lenses in the silt sample.

(b) The use of lignosol as an admixture reduced the amount of heave, the addition of four per cent liquor eliminating approximately ninety per cent. Samples containing ten per cent admixture showed no signs of heaving.

(c) Samples that did not contain lignosol started heaving at a higher air temperature than those that did.

5. Atterberg Tests - see Figure 11.

(a) Silt alone - liquid limit 18.6%
flow index 4.7
plasticity index 0

(b) Silt plus 10% lignosol - liquid limit 16.8%
flow index 4.5
plasticity index 0

6. Consolidation Tests - see Figures 12 to 17

(a) Silt alone - compressive index - 0.049
permeability (4000 g.) -0.34×10^{-6} cm/sec.

(b) Silt plus 10% lignosol - compressive index -0.070
permeability (4000 g.) - 1.01×10^{-6} cm/sec.

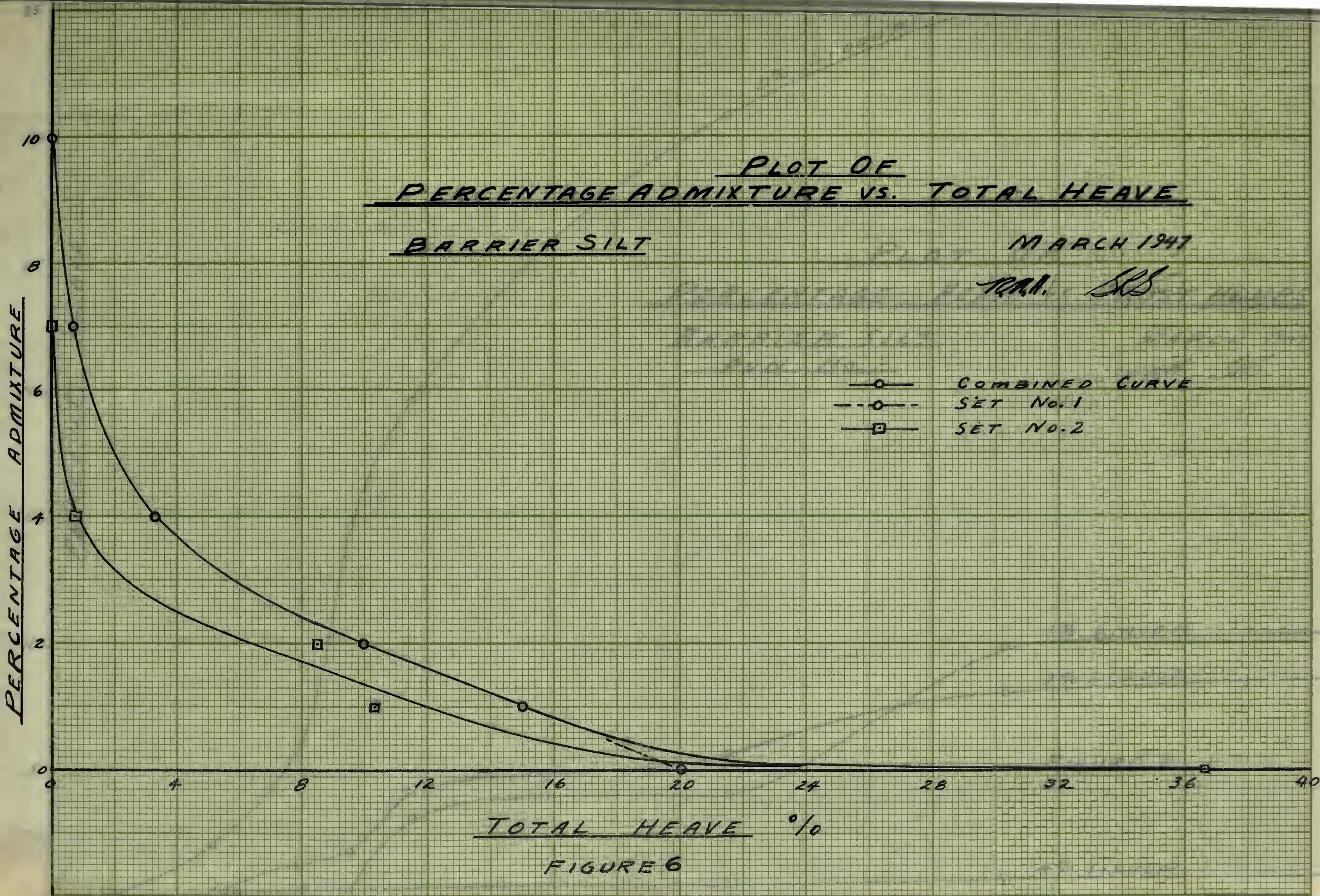
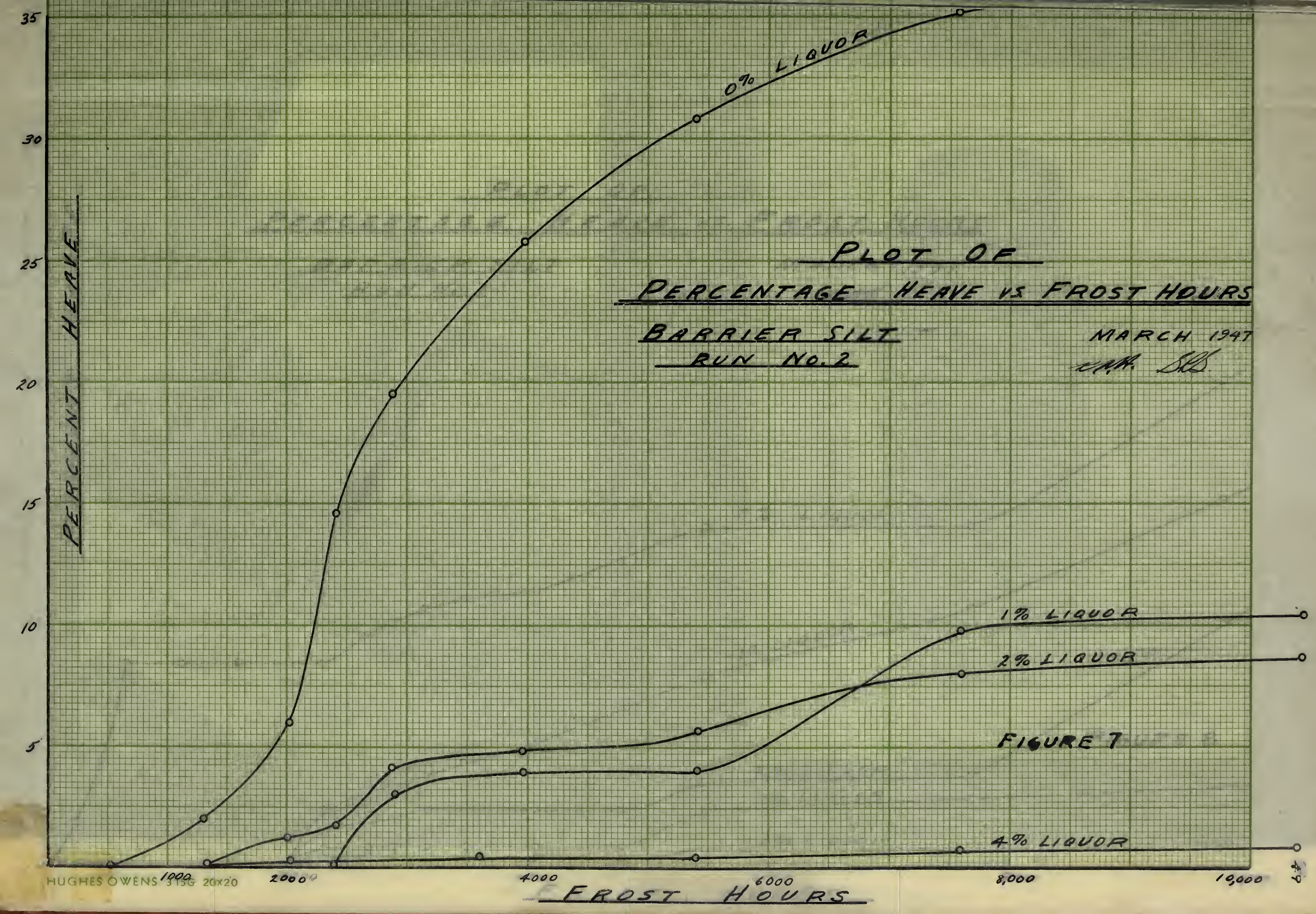


FIGURE 6

HUGHES OWENS 315G 20x20



PLOT OF

PERCENTAGE HEAVE VS FROST HOURS

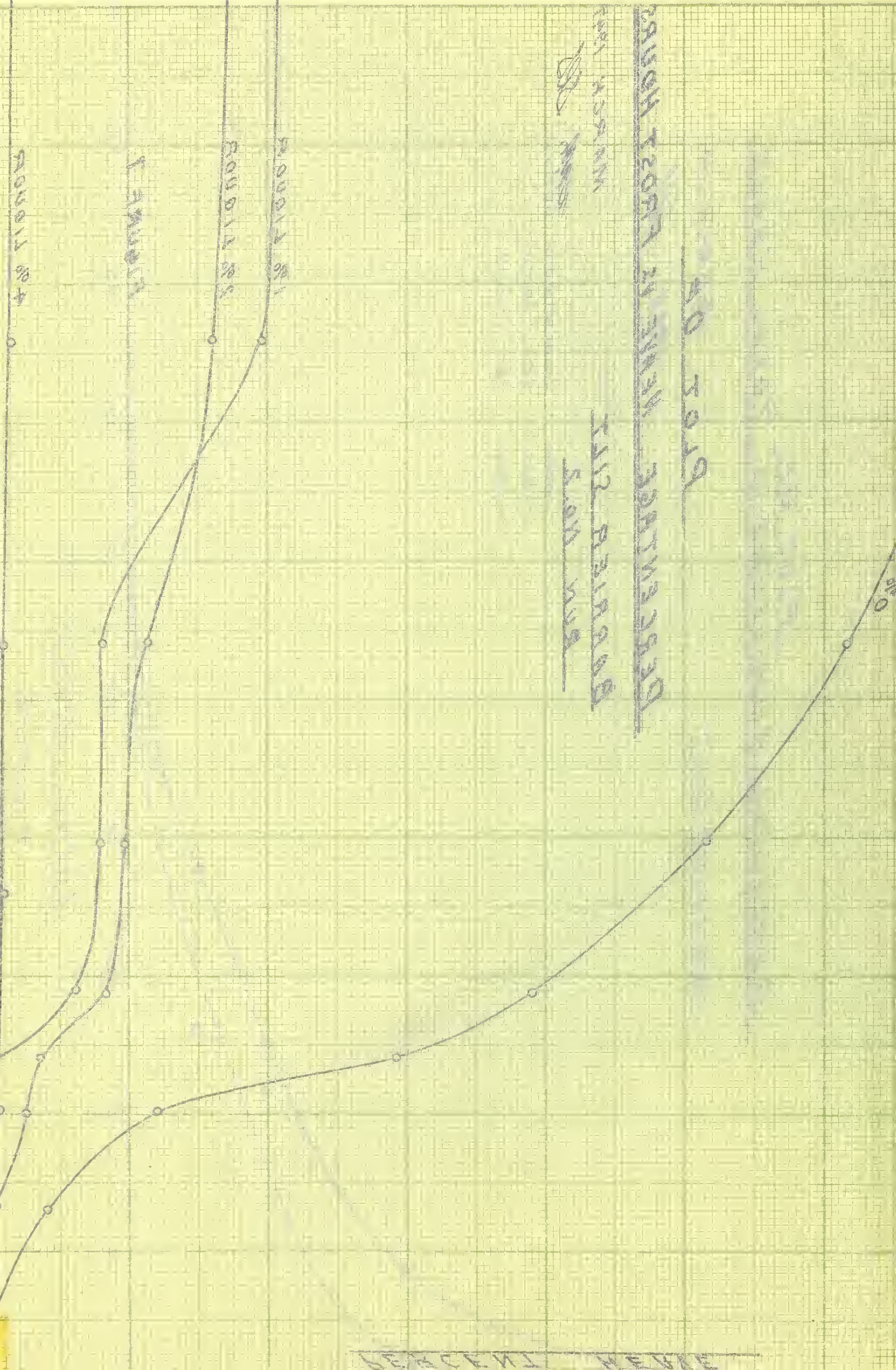
BARRIER SILT

RUN No. 2

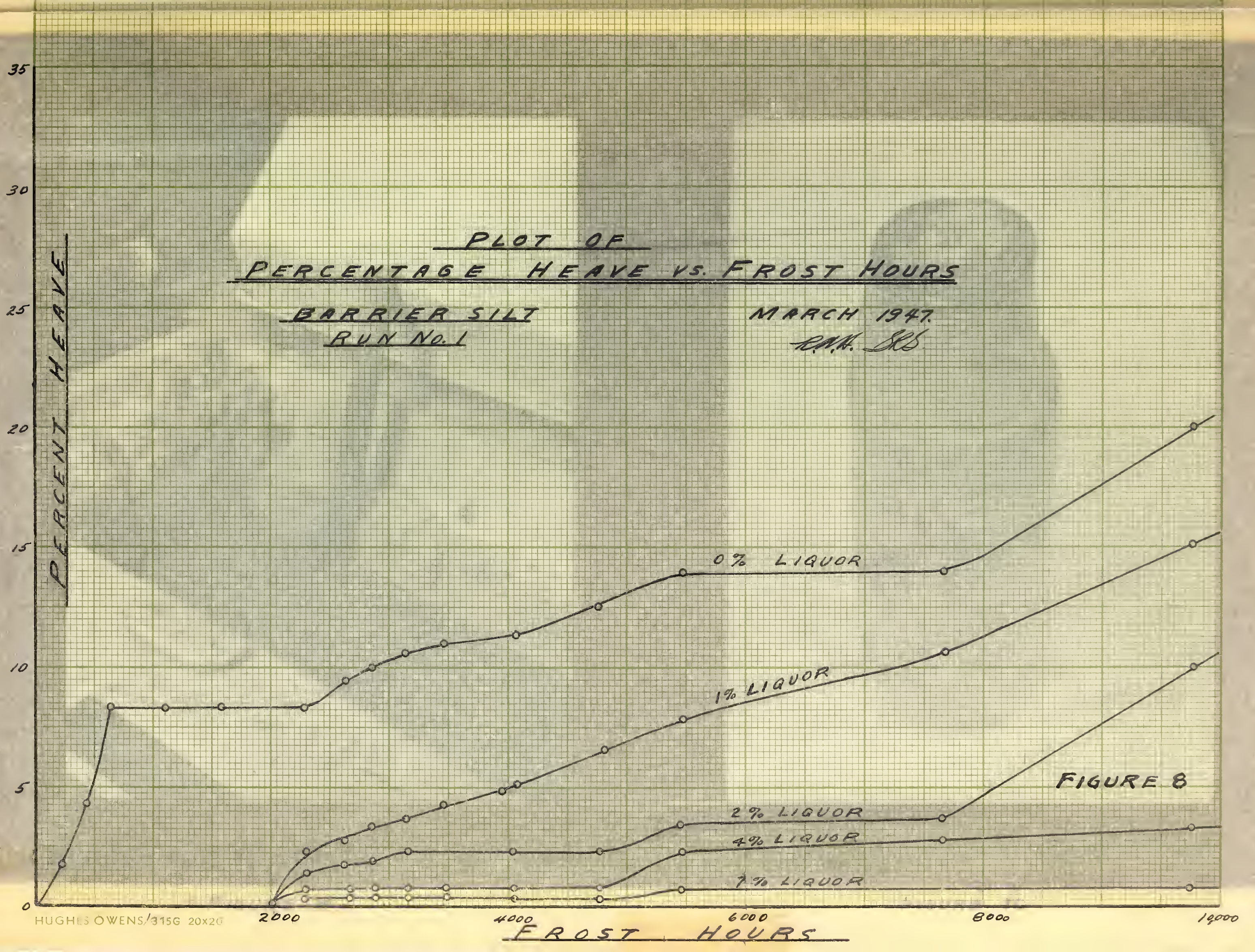
MARCH 1947

FIGURE 7

HUGHES OWENS 315G 20x20



Plot of
Percentage Heave vs Frost Hours
Barrier Silt
Run No. 2
March 1951
1% Liquor
2% Liquor
Figure 1
4% Liquor
0%
Percent Heave



PLOT OF
PERCENTAGE HEAVE VS. FROST HOURS

BARRIER SILT
RUN No. 1

MARCH 1947.

FIGURE 8

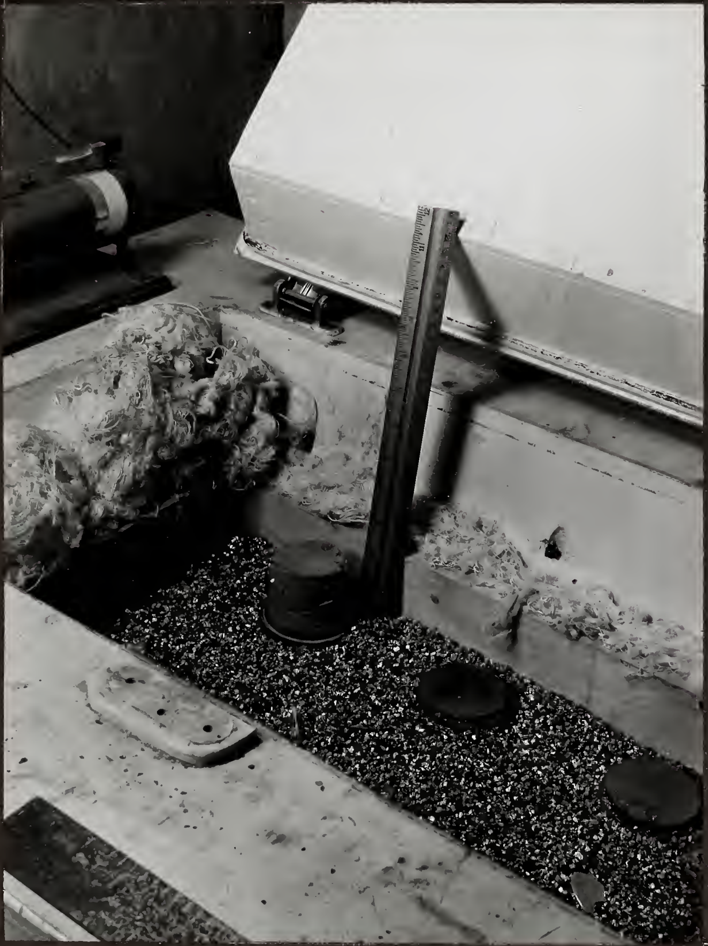


FIGURE 9

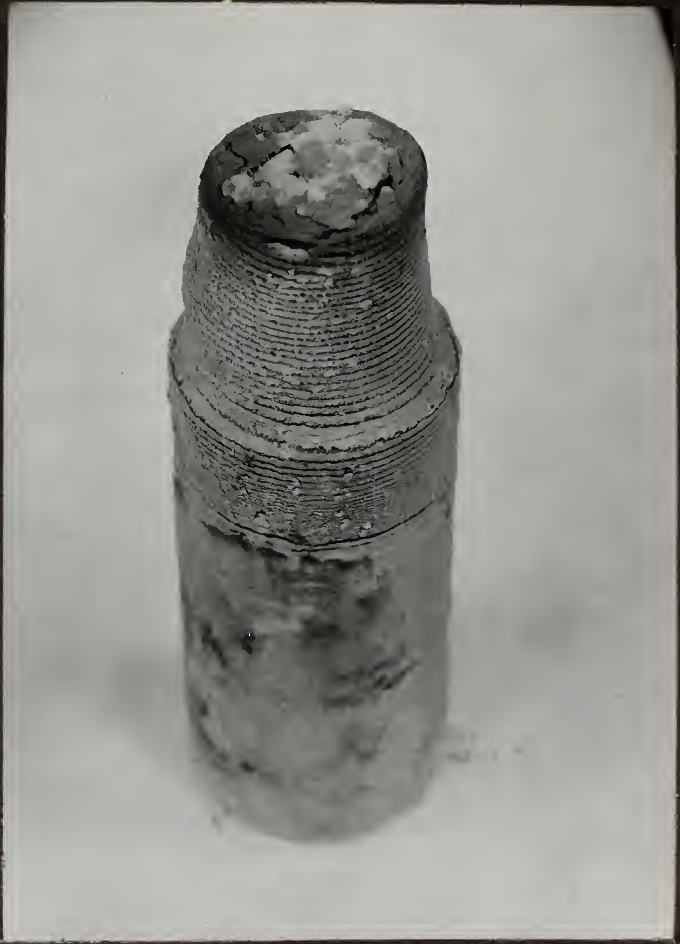


FIGURE 10

LIQUID LIMIT PLOTS.

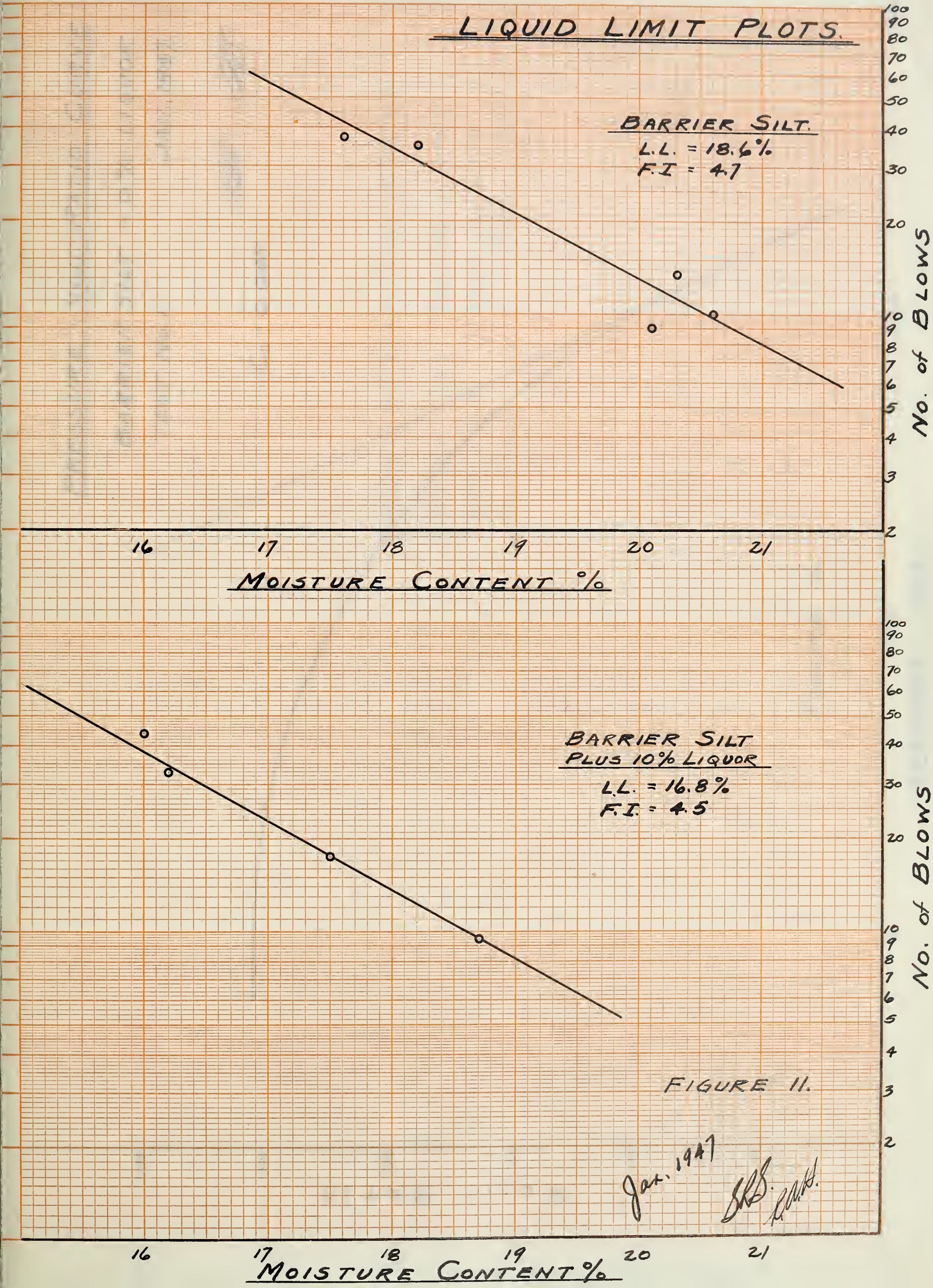
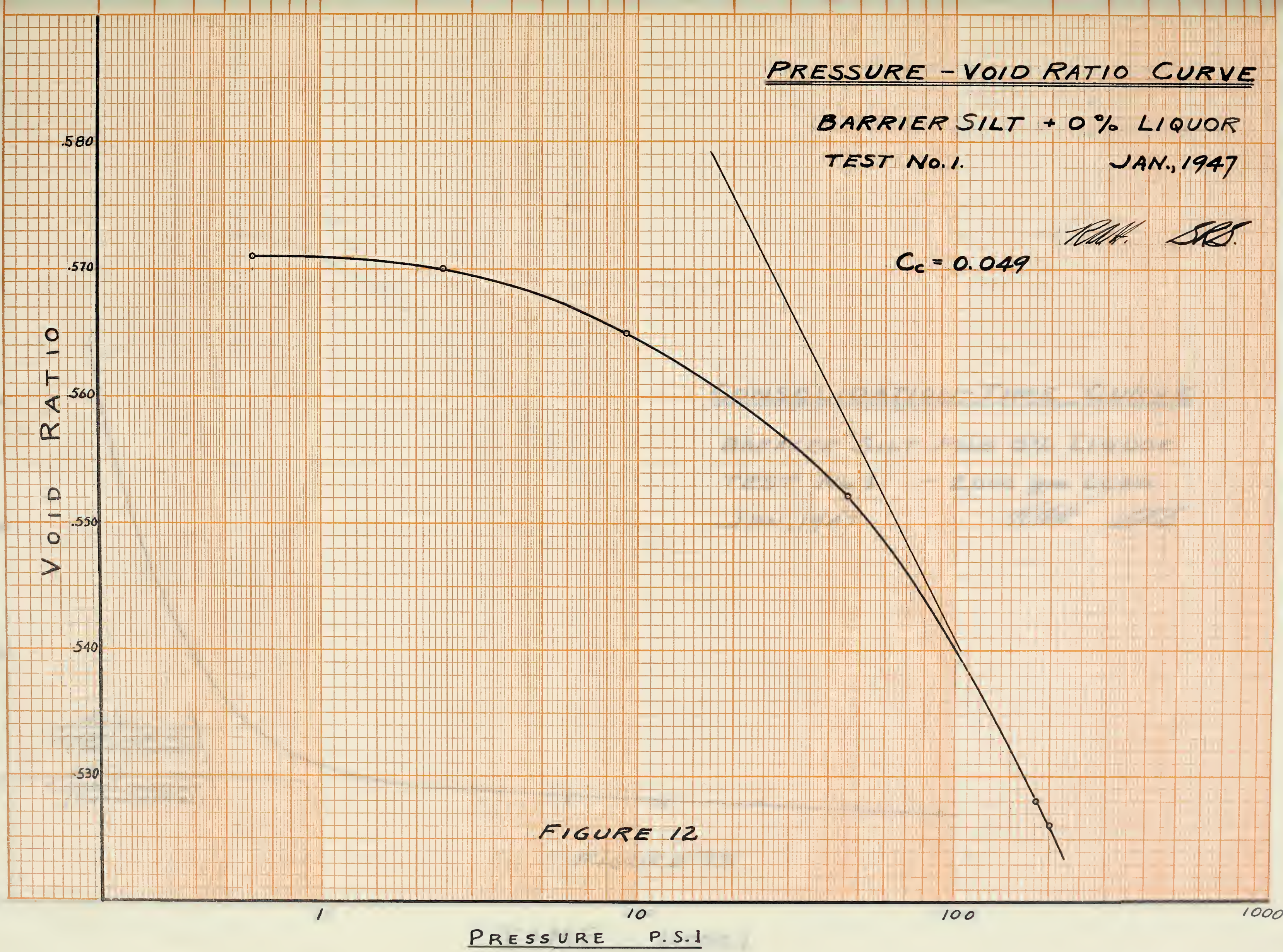


FIGURE 11.

Jan. 1947



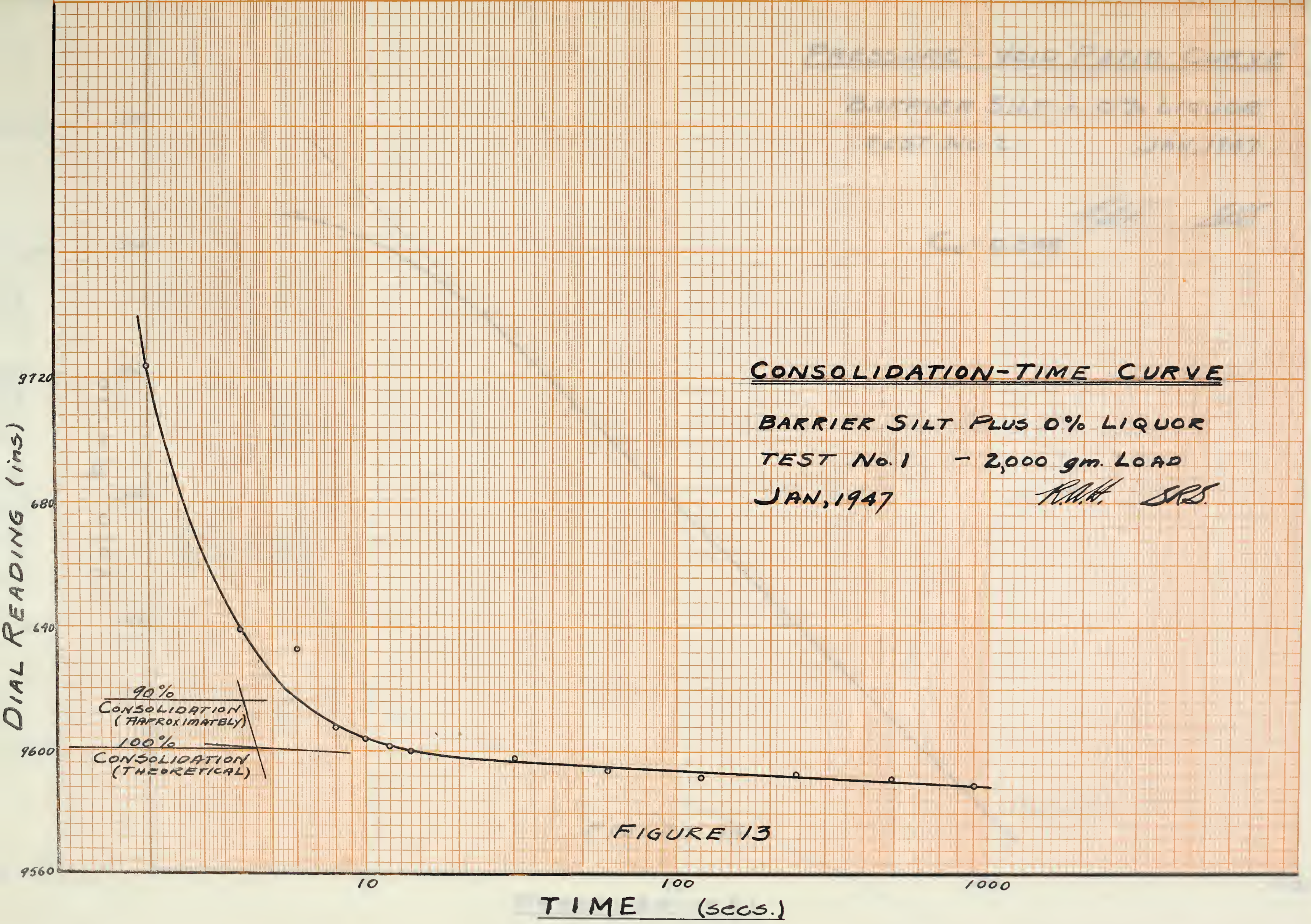
PRESSURE - VOID RATIO CURVE

BARRIER SILT + 0% LIQUOR

TEST No. 1. JAN., 1947

$C_c = 0.049$

FIGURE 12



CONSOLIDATION-TIME CURVE

BARRIER SILT PLUS 0% LIQUOR
TEST No. 1 - 2,000 gm. LOAD
JAN, 1947
R.W.H. S.R.S.

FIGURE 13

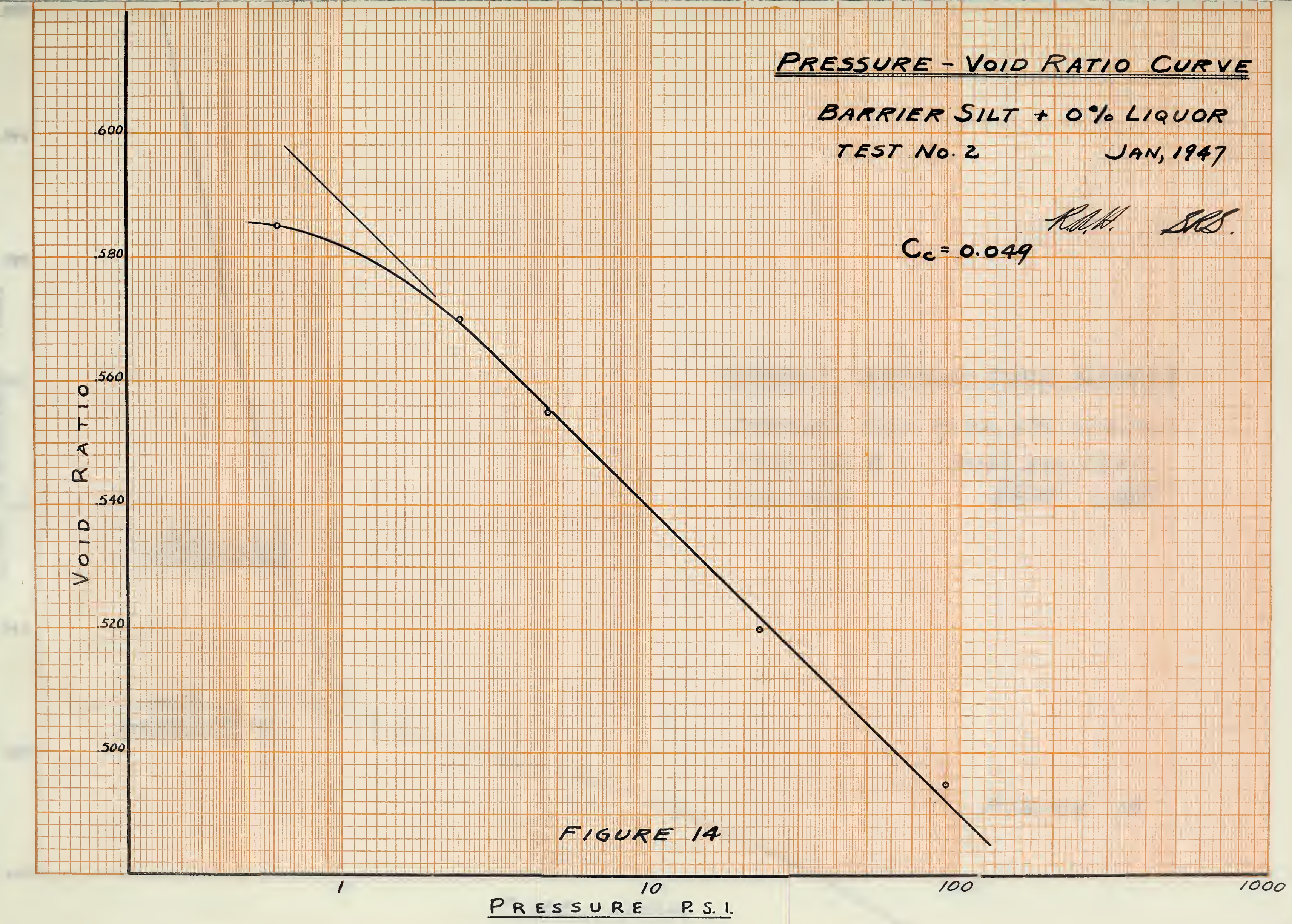
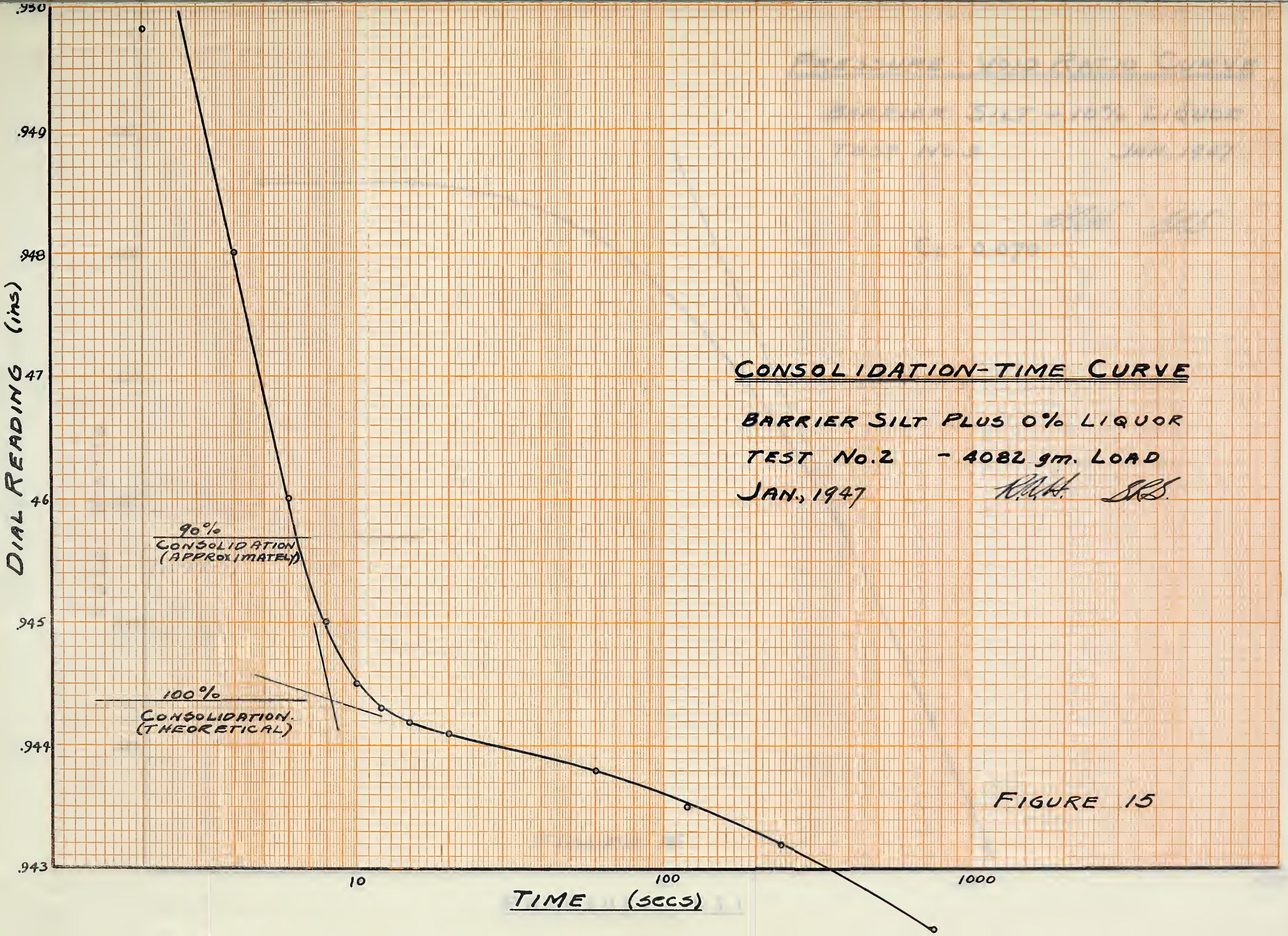

PRESSURE - VOID RATIO CURVE
BARRIER SILT + 0% LIQUOR
TEST No. 2
JAN, 1947
$C_c = 0.049$
VOID RATIO
.600
.580
.560
.540
.520
.500
1
10
100
1000
PRESSURE P.S.I.

FIGURE 14



CONSOLIDATION-TIME CURVE

BARRIER SILT PLUS 0% LIQUOR
TEST No. 2 - 4082 gm. LOAD
JAN., 1947 R.A.H. S.R.S.

FIGURE 15

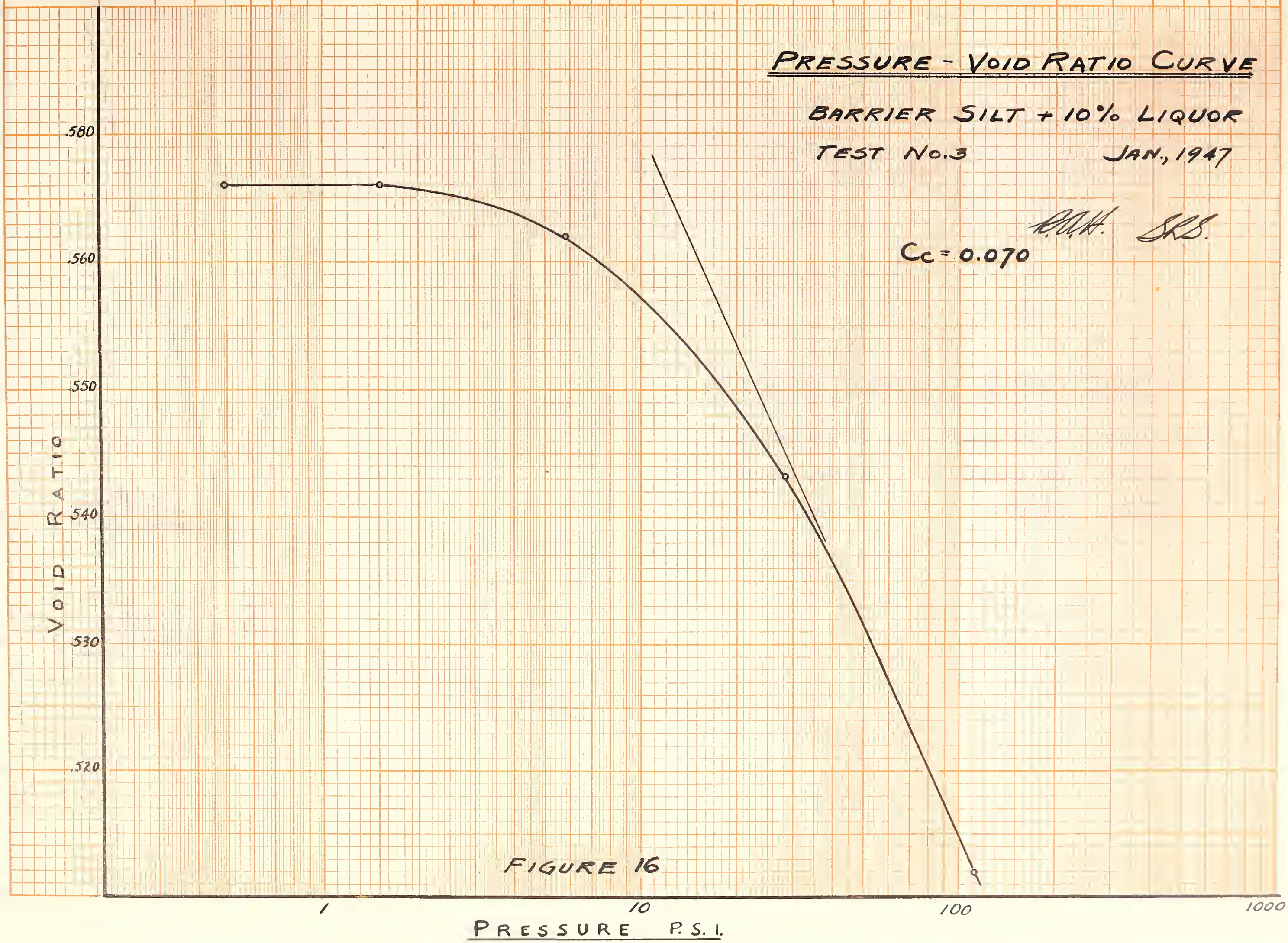
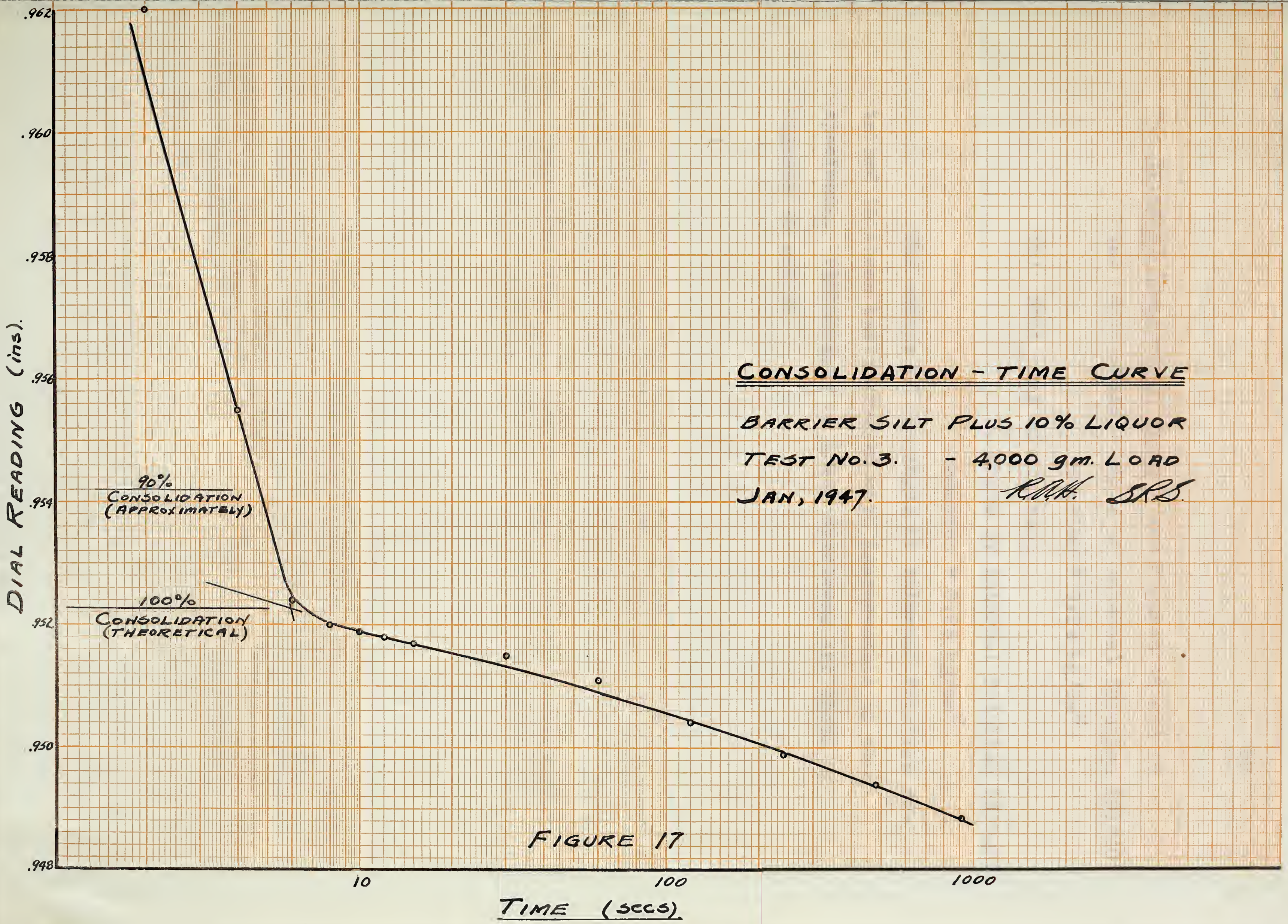

PRESSURE - VOID RATIO CURVE
BARRIER SILT + 10% LIQUOR
TEST No.3
JAN., 1947
Cc = 0.070
.580
.560
.550
.540
.530
.520
VOID RATIO
1
10
100
1000
PRESSURE P.S.I.

FIGURE 16



CONSOLIDATION - TIME CURVE

BARRIER SILT PLUS 10% LIQUOR

TEST No. 3. - 4,000 gm. LOAD

JAN, 1947. R.R.H. S.R.S.

FIGURE 17

7. Triaxial Compression Tests - see Figures 18 and 19

(a) Silt alone - angle of internal friction (ø)=40°
cohesion = 0.24 kg/cm^2

(b) Silt plus 4% lignosol
- angle of internal friction (ø)=40°
cohesion = 0.25 kg/cm^2

The values of the angle of internal friction obtained in these tests checked with measurements of the specimens. Photographs of these specimens are shown in Figures 20 and 21.

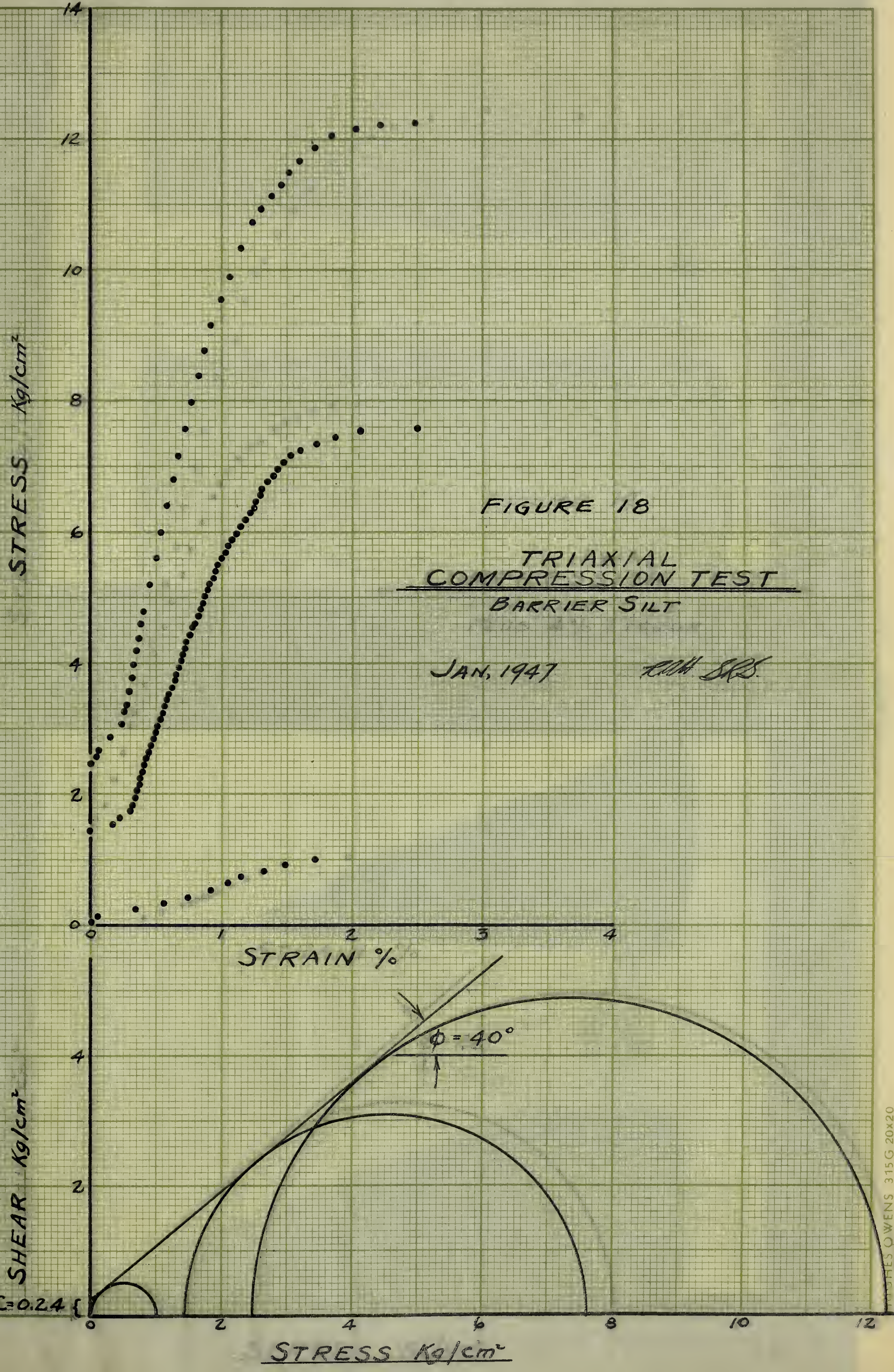


FIGURE 18

TRIAXIAL COMPRESSION TEST

BARRIER SILT

JAN, 1947 RWH. SRS.

HUGHES OWENS 315 G 20x20

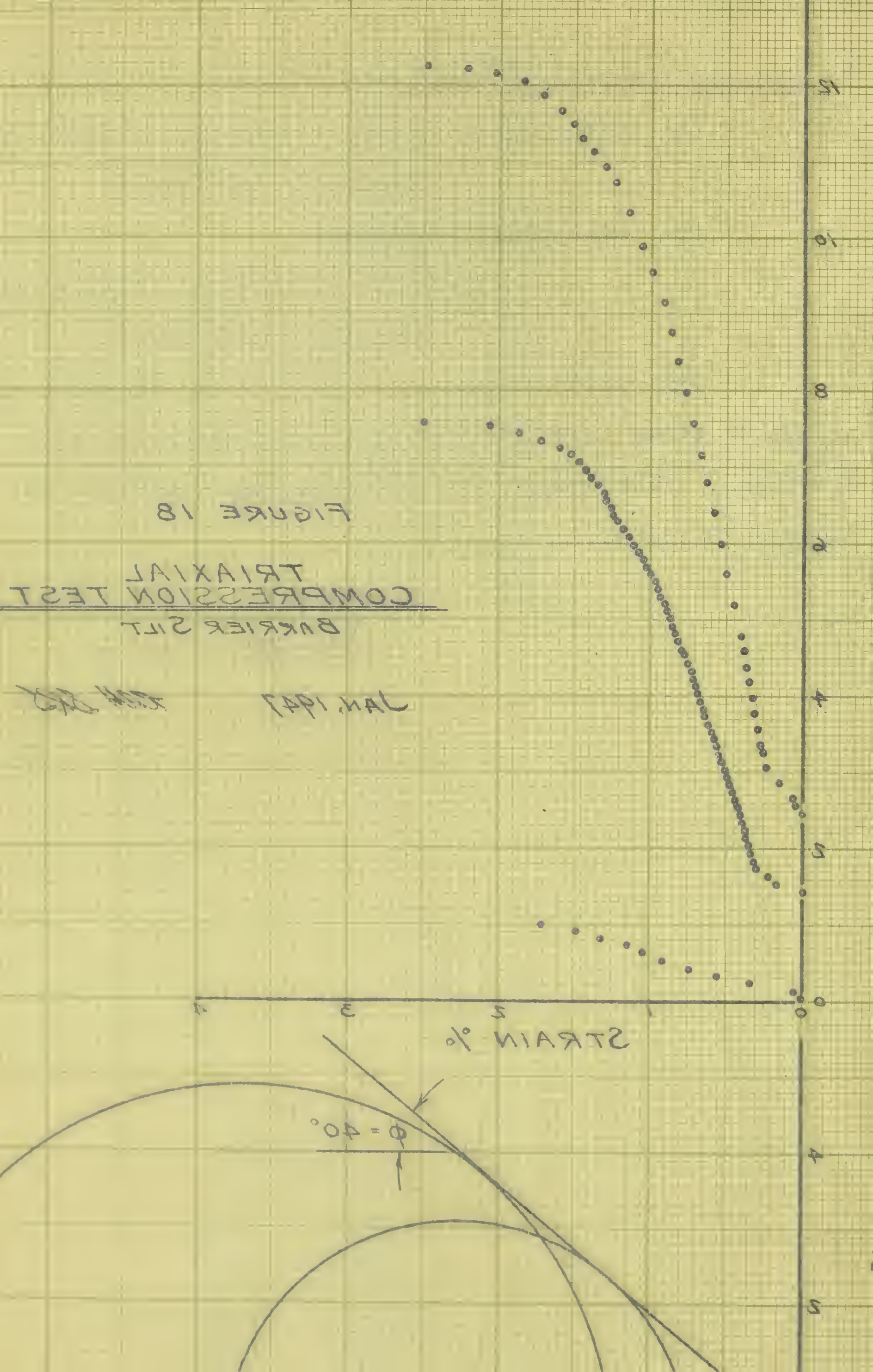


FIGURE 18
TRIAXIAL COMPRESSION TEST
BARRIER SILT
JAN. 1947
STRAIN %
Φ = 40°
0
1
2
3
4
2
4
6
8
10
12
4
2

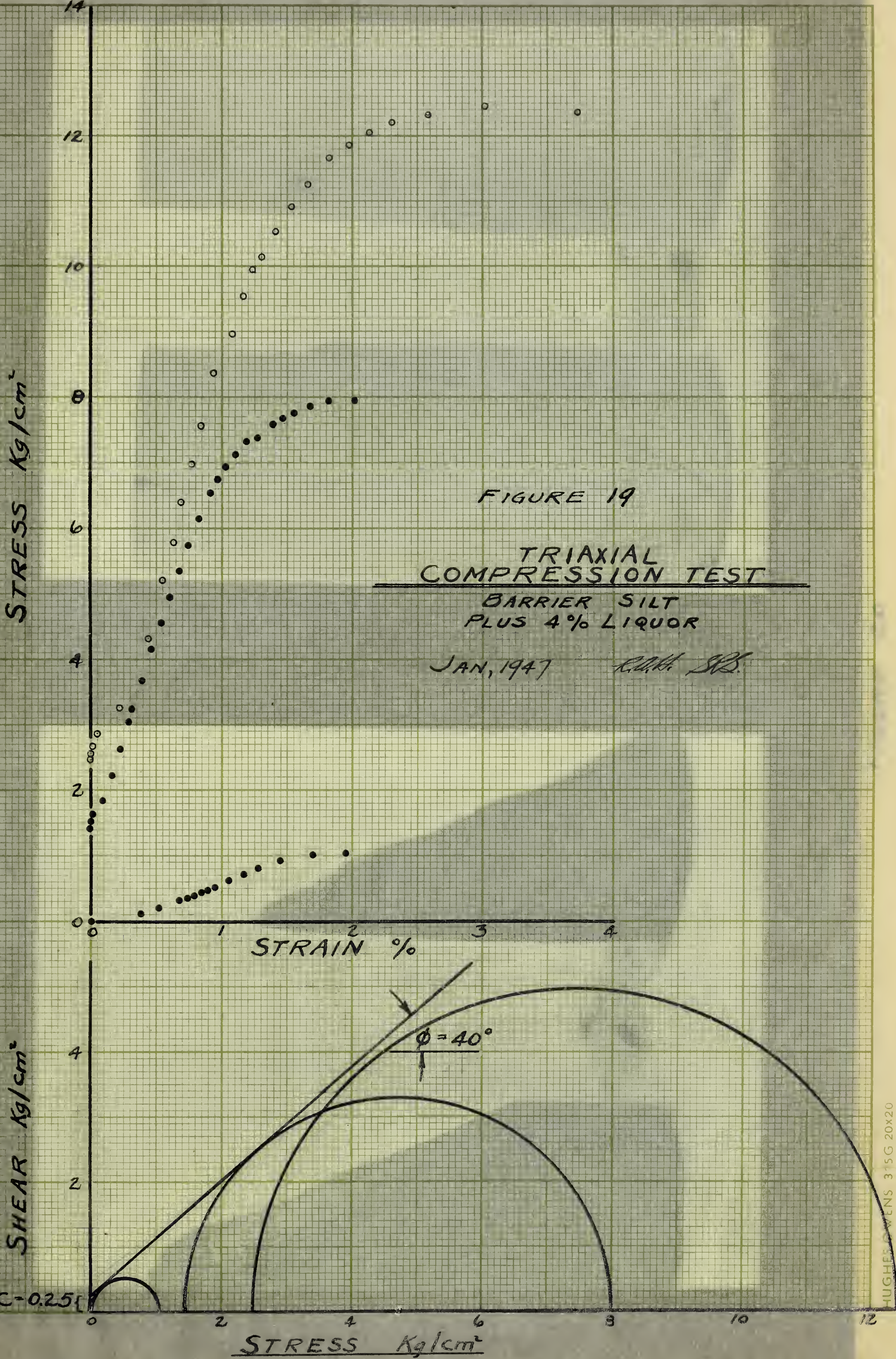


FIGURE 19

TRIAXIAL COMPRESSION TEST

BARRIER SILT
PLUS 4% LIQUOR

JAN, 1947

HUGHES OWENS 315G 20x20

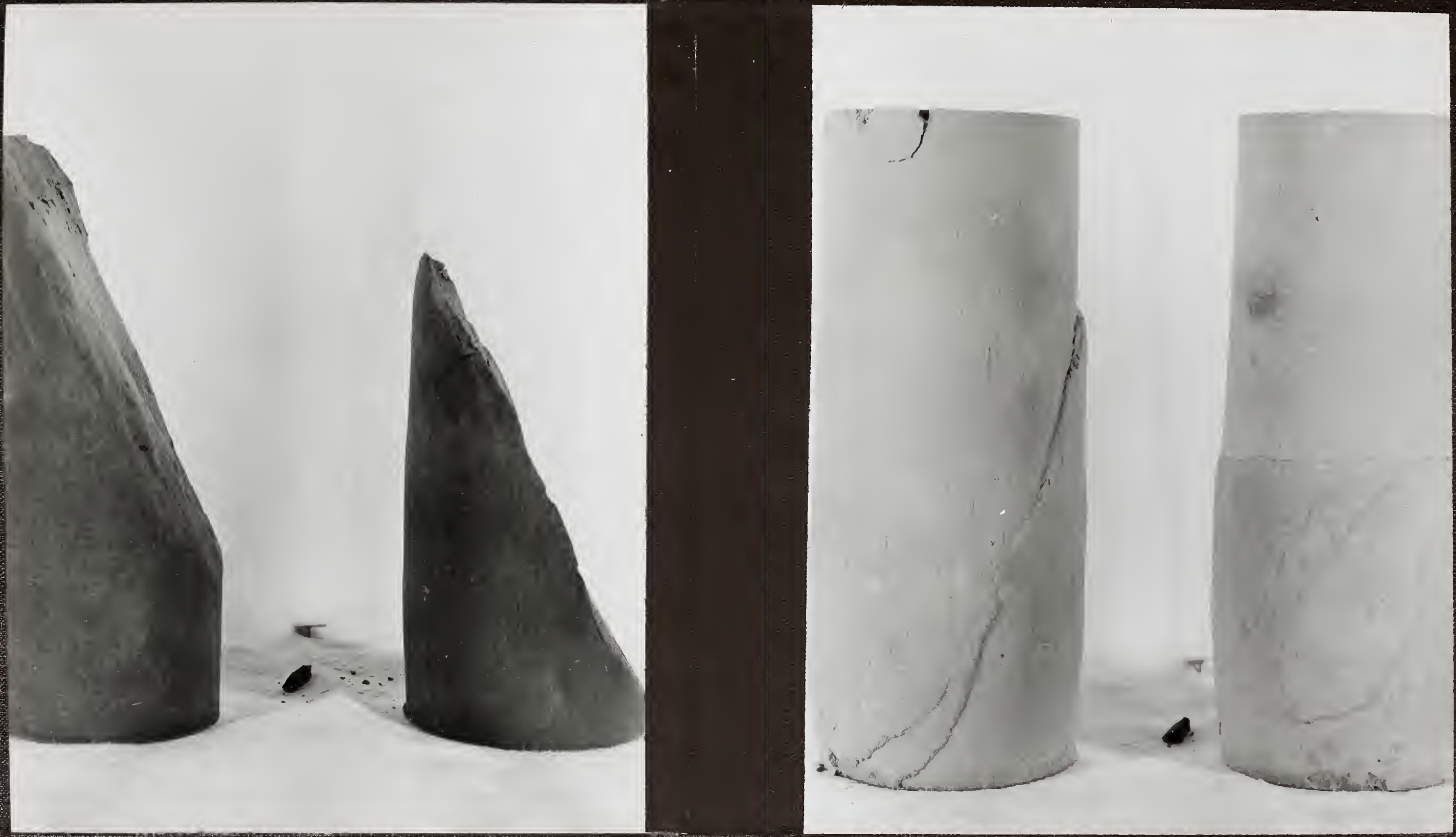


FIGURE 20

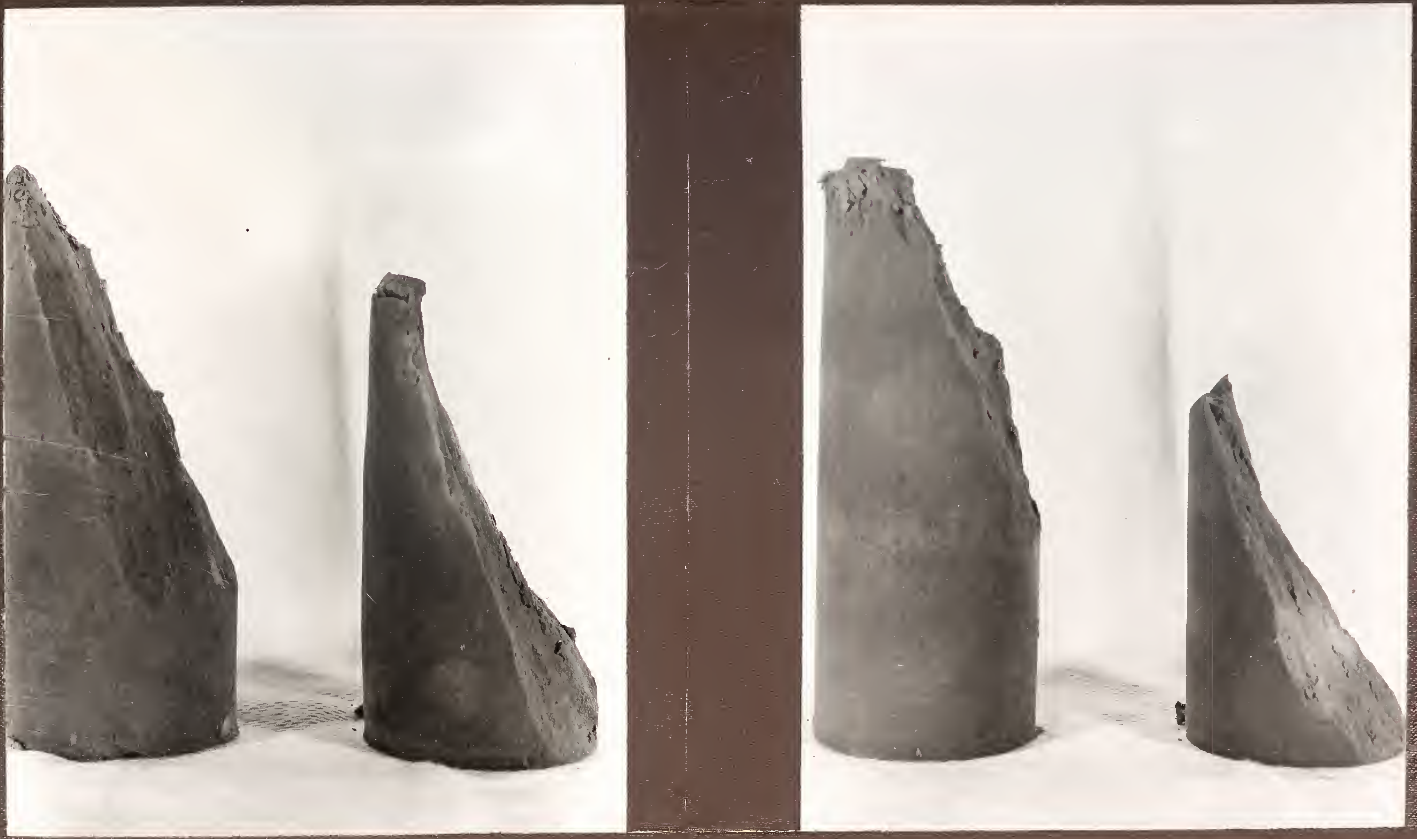


FIGURE 21

VII

DISCUSSION

The maximum heave obtained in this test was only about half the maximum obtained by Winn and Rutledge(18). This discrepancy is due to a lack of good temperature control, or use of a different soil, or both. However, the heaves recorded are great enough to indicate conclusively that lignosol does reduce frost heaving in this soil.

There are two possible explanations for the action of the liquor in reducing this heaving. They are:-

(a) A lowering of the freezing point of the soil moisture.

(b) A reduction in the capillary forces due to the wetting properties of the lignosol.

It is believed by the authors, that both are applicable in this case.

The results of this investigation indicate that lignosol may have value in reducing frost heaving in highways and airports. Its use in practice however, would depend on several considerations.

First, the comparative cost of this method to other methods currently employed. If 4% liquor was used, the approximate cost of the liquor would be $1.00 per yard of soil. Whether this would be economical or not would depend on the particular job. In most cases however, the methods used at present involve a cost of far more than this.

Secondly, the length of time the lignosol can be

expected to be effective. The most important use of an admixture to deter frost action would be for treating the subgrades of highway and airport pavements. When used for this purpose, it is likely that the admixture, although soluble in water, would not be leached out because of the protection given by the pavement. This would have to be verified by field trials.

Thirdly, probable methods of application. The application of liquor to new fills presents no serious difficulty. Because it is soluble in water and readily mixed, it could be applied directly by spraying the borrow pit or the fill. This would be most advantageous if the soil was initially in a dry state. If the soil is already in place, the lignosol could still be added by spraying. It is possible that the admixture would permeate the soil sufficiently to prevent frost action. Some reworking of the soil in place might be necessary if spraying alone was found to be inadequate.

The standard optimum density of the silt alone is 110 lbs. per cu.ft. at a moisture content of 14.5%. With the addition of this admixture, the optimum density increases, the optimum moisture decreases, and the curves become steeper as shown in Figure 2. It is to be noted that moisture control is very important with soil containing admixture. With good moisture control, the lignosol gives higher densities than may be obtained with the silt alone. On the other hand, soil containing admixture and compacted at 14.5% moisture

gives a density approximately 15% less than that obtained with silt alone.

VIII

CONCLUSIONS

1. Lignosol deters frost action on the soil tested.

2. It has a marked effect on the compaction properties of this soil.

3. It does not ~~appreciable~~ appreciably change the plasticity of this soil.

4. It does not change the consolidation characteristics or the permeability of this soil.

5. It does not alter the shearing strength of this soil.

6. The results of this study are sufficiently encouraging to warrant further laboratory and field investigation.

IX

RECOMMENDATIONS FOR FURTHER STUDIES

Further investigation is necessary to determine the practical use of lignosol in deterring frost action in highway and airport subgrades.

It is the opinion of the authors that this work should include:-

1. A laboratory study of the effect of lignosol in deterring frost action in a wide range of susceptible soils. Improved methods of temperature control would facilitate obtaining conclusive results. Refrigeration equipment similar to that used at Purdue(18) is recommended.

2. A comparative study of the effect of calgon and other wetting agents when used as admixtures in these same soils.

If some of these other wetting agents were also effective in reducing heaving in soils, an economic comparison could then be made. In this connection, the possibility of separating the effective constituents of lignosol should be considered.

3. Field tests to confirm laboratory results. These field tests should cover the same wide range of soils susceptible to frost. The duration of the effectiveness of the admixture should be determined in these tests. Experiments in spraying and mixing of the soil should also be conducted.

X

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XI

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